

Late Paleocene to early Eocene planktic foraminiferal biostratigraphy of the Dungan Formation, Sulaiman Range, central Pakistan

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Abstract. The Paleogene marine sequences of the Dungan, Shaheed Ghat, Baska and Kirthar Formations are exposed at several places in the Sulaiman fold and thrust belt in central Pakistan. The lowermost Dungan Formation unconformably overlies the open marine Maastrichtian Pab Sandstone, being distributed widely along both limbs of the Zinda Pir Anticline area and in the Rakhi Nala area. The Dungan Formation is composed mainly of black-colored siltstone with some intercalations of sandstone in the base and many interbeds of limestone in the upper part. The strata from all three sections have yielded abundant and well-preserved Paleocene-Eocene planktic foraminifers and about 50 species belonging to nine genera are identified from this sequence. Zones P3 to P7 of the tropical zonal schemes were recognized, furthermore, Zones P3 and P4 are subdivided into two subzones (Subzones A and B), respectively. These assemblages contain a new species *Globanomalina rakhiensis* in the Rakhi Nala section. A late Paleocene through early Eocene age is assigned to the Dungan Formation. The quantitative data of each species indicates that the Dungan Formation was deposited in a relatively deep to open marine environment, probably forming a continental slope dipping from east to west.

Key words: Biostratigraphy, Dungan Formation, Pakistan, Paleocene-Eocene, paleoenvironment, planktic foraminifera, Sulaiman Range

Introduction

A Mesozoic to Paleogene sedimentary sequence is widely exposed along the northwestern margin of the Indian Subcontinent in central Pakistan. These strata were deposited during the closing of the Tethys Ocean and form several fold-and-thrust belts of over 100 km width along a series of lobes in the Kirthar, Sulaiman, and Salt Ranges from south to north (Cheema *et al.*, 1977; Humayon *et al.*, 1991; Warwick *et al.*, 1998). The Paleogene sequence of the Sulaiman Range which overlies the Mesozoic marine shelf sediments consists of the Paleocene to Eocene Dungan Formation, the early Eocene Shaheed Ghat and Baska Formations, and the middle to late Eocene Kirthar Formation. Latif (1961) and Samanta (1973) reported many Paleocene-Eocene planktic foraminifers and their zonation from the Rakhi Nala section located in the eastern Sulaiman Range (Figure 1). Jones (1997) also showed the age of the Dungan Formation using the planktic foraminifers recovered

from three samples from the northern part of the Sulaiman Range. Warraich and Natori (1997) also established the Paleocene-Eocene planktic foraminiferal biostratigraphy on the western side of the Zinda Pir Anticline region, and recognized the following nine zones: the *Morozovella angulata*, *Globanomalina pseudomenardii*, *Morozovella velascoensis*, *M. subbotinae*, *M. formosa formosa*, *M. aragonensis*, *M. spinulosa/Truncorotaloides topilensis*, *Catapsydrax howei* and *Globigerina officinalis* zones. However, this biostratigraphic work is still preliminary and further detailed work is needed for correlation with the recently revised standard zonal schemes of Berggren *et al.* (1995) and Olsson *et al.* (1999).

The main objectives of this paper are to establish a complete biostratigraphic zonation of the Dungan Formation distributed in the Zinda Pir Anticline and the Rakhi Nala regions of the Sulaiman Range, and to correlate zones established in these regions with standard zones of the tropical-subtropical latitudes, and with those recognized in the other

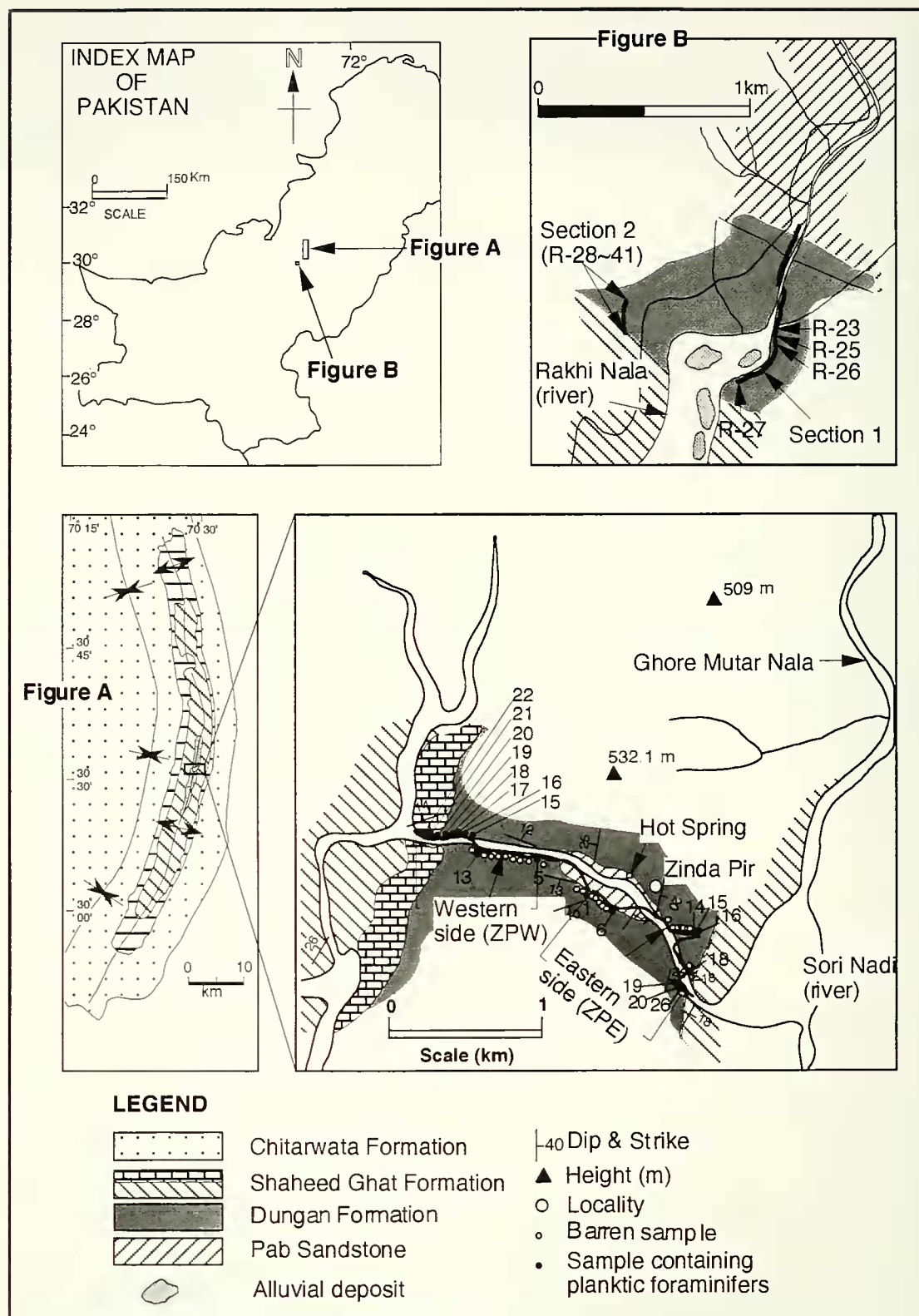


Figure 1. Route maps of the Rakhi Nala and the Zinda Pir sections of the eastern Sulaiman Range, central Pakistan.

regions of the Indus Basin. We also discuss the faunal changes and depositional environment of the Dungan Formation using quantitative foraminiferal data.

Materials and methods

We carried out systematic sampling along both sides of the Zinda Pir Anticline and in the Rakhi Nala section covering the entire sequence of the Dungan Formation (Figure 1). Some 54 samples (22 samples coded ZPW and 32 samples coded ZPE) were obtained along the western and the eastern limbs of the Zinda Pir Anticline, and 41 samples (coded R) were collected from the Rakhi Nala section. These samples were collected at 1- to 5-meter intervals. Because siltstone samples were very hard, all samples (each weighing 100g) were first treated with sodium sulfate (Na_2SO_4), and later with tetraphenylborate (NaTPB). The disaggregated samples were washed using a 63 μm sieve.

Population counts for planktic foraminifers are based on random splits of 200 to 300 specimens. To remove juvenile forms, specimens over 150 μm were picked and identified; however, the smaller fractions were also scanned for recognition of small-sized species. The faunal reference list is given in Appendix 1.

Lithostratigraphy

The Paleogene sequences exposed in the Zinda Pir and Rakhi Nala sections of the investigated areas consist of the Dungan and the Shaheed Ghat Formations in ascending order (Figure 1). The Dungan Formation forms the basal part of the Paleogene sequence, unconformably overlying the Maastrichtian Pab Sandstone (Kazmi, 1995, Nomura and Brohi, 1995, this study). Eames (1952) was the first who described the lithostratigraphy of the lower Paleogene strata of both the Zinda Pir and Rakhi Nala areas in detail. He divided this sequence into four lithological units in both areas (Figure 2). Cheema *et al.* (1977) and Kazmi (1995) summarized his several units and gave the name of the Dungan Formation to the mudstone-dominated sequences. For example, Kazmi (1995) included many lithological units

defined by many previous workers into the Dungan Formation (Figure 2).

We divided the strata distributed in the studied area into three formations according to the lithology of Kazmi (1995). The lowermost strata of the Maastrichtian Pab Sandstone consist of white, cream-to brown-colored, thick- to massive-bedded, medium to coarse-grained quartzose sandstone with intercalations of shale and argillaceous limestone in the study areas. The Dungan Formation overlying the Pab Sandstone represents dark-black colored siltstones interbedded with hard quartzitic-glaucconitic sandstone beds in the lower part and thin-to thick-bedded, dark-gray limestone weathering brown-buff in the upper part. The interbeds of sandstone are abundant in the Rakhi Nala, while those of limestone are common in the Zinda Pir.

It is noteworthy that the thickness of the Rakhi Nala section (312 m) is twice that of the Zinda Pir sections (135 m). In the Sulaiman Range, while contact of the Dungan Formation with the overlying Shaheed Ghat Formation is described as conformable (Cheema *et al.*, 1977; Shah, 1990, Kazmi, 1995). However, we describe this contact as unconformable based on the presence of the conglomeratic to brecciated limestone bed in the lowermost part of the Shaheed Ghat Formation (Figures 3-6). Previous workers (Eames, 1952; Cheema *et al.*, 1977; Shah, 1990, Kazmi, 1995) did not report this conglomeratic to brecciated limestone bed. Moreover, this result is also supported by the nonexistence of Zone P6 (Figures 3-6). Thickness of the conglomeratic to brecciated limestone bed is 16 m in the Zinda Pir sections that pinches out at Rakhi Nala. However, in the Rakhi Nala section, there is another conglomeratic to brecciated bed (1 m) which is stratigraphically younger than those of the Zinda Pir sections (Figure 6). This limestone contains shallow marine fossils such as larger foraminifers and bivalves (*Vasticardium* and *Chlamys* species) embedded in a calcareous matrix containing a pelagic fauna.

Biostratigraphy

Among 32 and 22 samples collected from the Dungan

Eames (1952)		Cheema et al. (1977)	Kazmi (1995)	This work
Rakhi Nala	Zinda Pir			
Upper Rakhi Gaj Shales	Ghazij Shales	Ghazij Fm.	Shaheed Ghat Formation	Shaheed Ghat Formation
	Zinda Pir Ls. (upper part)			
Lower Rakhi Gaj Shales	Zinda Pir Ls. (lower part)	Dungan Fm.	Dungan Formation	Dungan Formation
	Zinda Pir Shales			
Gorge Beds	Quartzose Sandstone	Bara Fm.		
Venericardia Shales		Khadro Fm.		
Pab Sandstone		Pab Sandstone	Pab Sandstone	Pab Sandstone

Figure 2. Lithostratigraphic subdivisions and correlation of the early Tertiary strata exposed in the Sulaiman Range proposed by different workers.

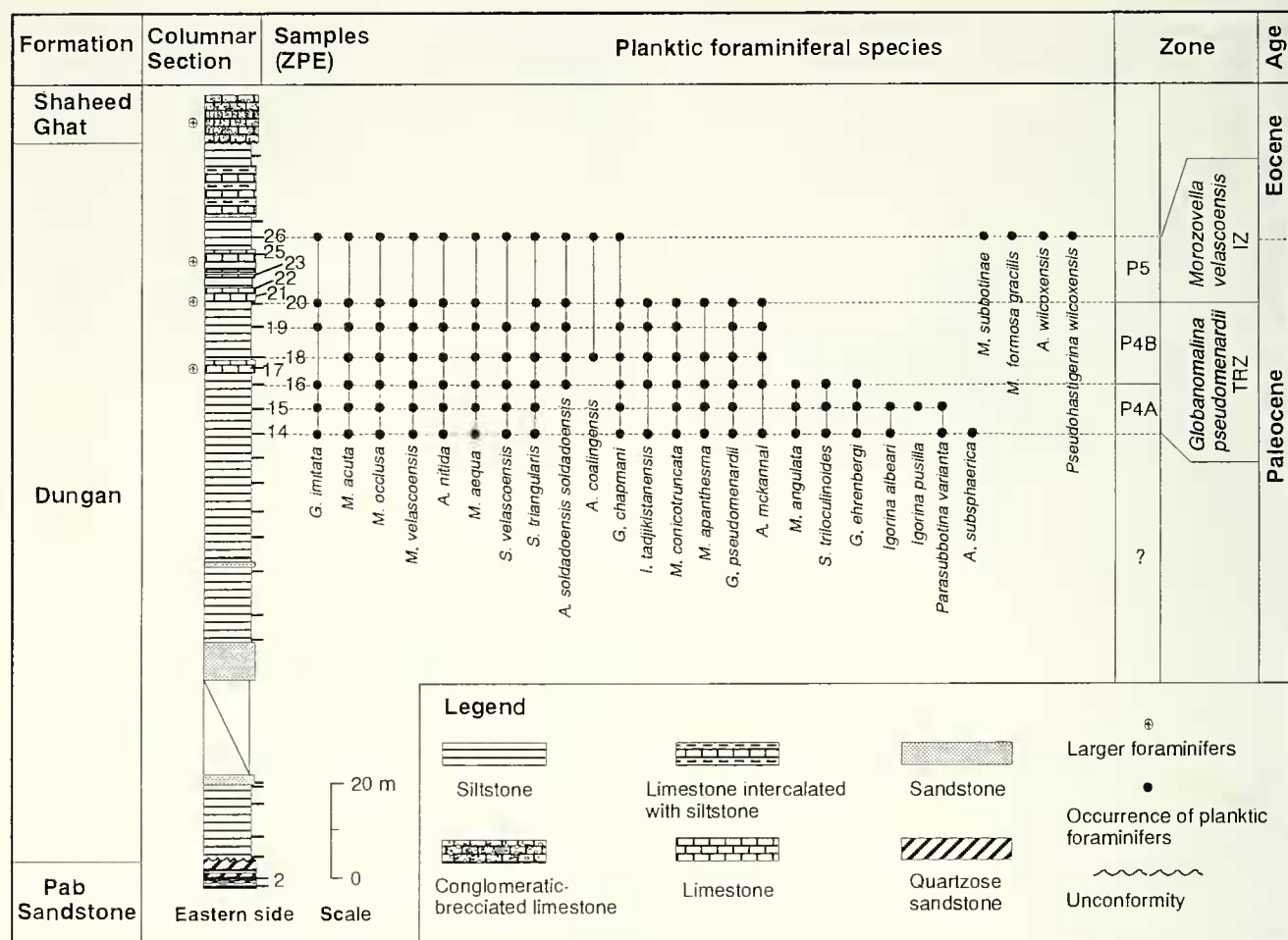


Figure 3. Measured columnar section along the eastern limb of the Zinda Pir Anticline showing lithostratigraphic sequences, sample locations, and biostratigraphic distribution of the recovered planktic foraminifers. The numbers indicate the samples containing planktic foraminifers.

Formation along the eastern and western limbs of the Zinda Pir Anticline, 7 and 11 samples yielded planktic and benthic foraminifers, respectively. The individual specimens of the planktic foraminifers recovered from the western side of the Zinda Pir Anticline are abundant and better preserved than those from the eastern side. Some 30 species belonging to 7 different genera of planktic foraminifers were identified in the Zinda Pir sections (Appendix 3).

In the Rakhi Nala section, 16 samples out of 41 yielded abundant and well-preserved foraminifers. The planktic foraminiferal assemblage recovered from this section comprised 51 species belonging to 10 genera (Appendix 3).

Two standard Paleogene zonal schemes have been established in the low-latitude regions. One is represented by Bolli's zonation and its revisions (Bolli, 1957, 1966; Toumarkine and Luterbacher, 1985). The other one is the P-zonation of Blow (1979) and its modifications (Berggren and Miller, 1988; Berggren *et al.*, 1995). Recently, Berggren and Norris (1997) and Olsson *et al.* (1999) have

published updated versions of the Paleocene P-zonal system and the phylogeny.

The Paleogene fauna recovered from the Dungan Formation included abundant tropical and subtropical indicators, suggesting a habitat of tropical-subtropical Tethyan waters. Hence, the Paleogene international zonal schemes proposed by Berggren *et al.* (1995) and Olsson *et al.* (1999) are basically applicable to the faunal assemblage of the Dungan Formation (Figure 7). This formation is divided into five biostratigraphic intervals that correspond to Zones P3 to P7 of Berggren's zonation (Figure 7). However, we have subdivided Zone P4 of Berggren and Norris (1997) and Olsson *et al.* (1999) into two subzones instead of three as an extension of the stratigraphic range of *A. subsphaerica* is recorded in this region. Moreover, we have used some different datum levels as boundaries of subzones due to sporadic occurrence of index species in the lower portions of all three sections.

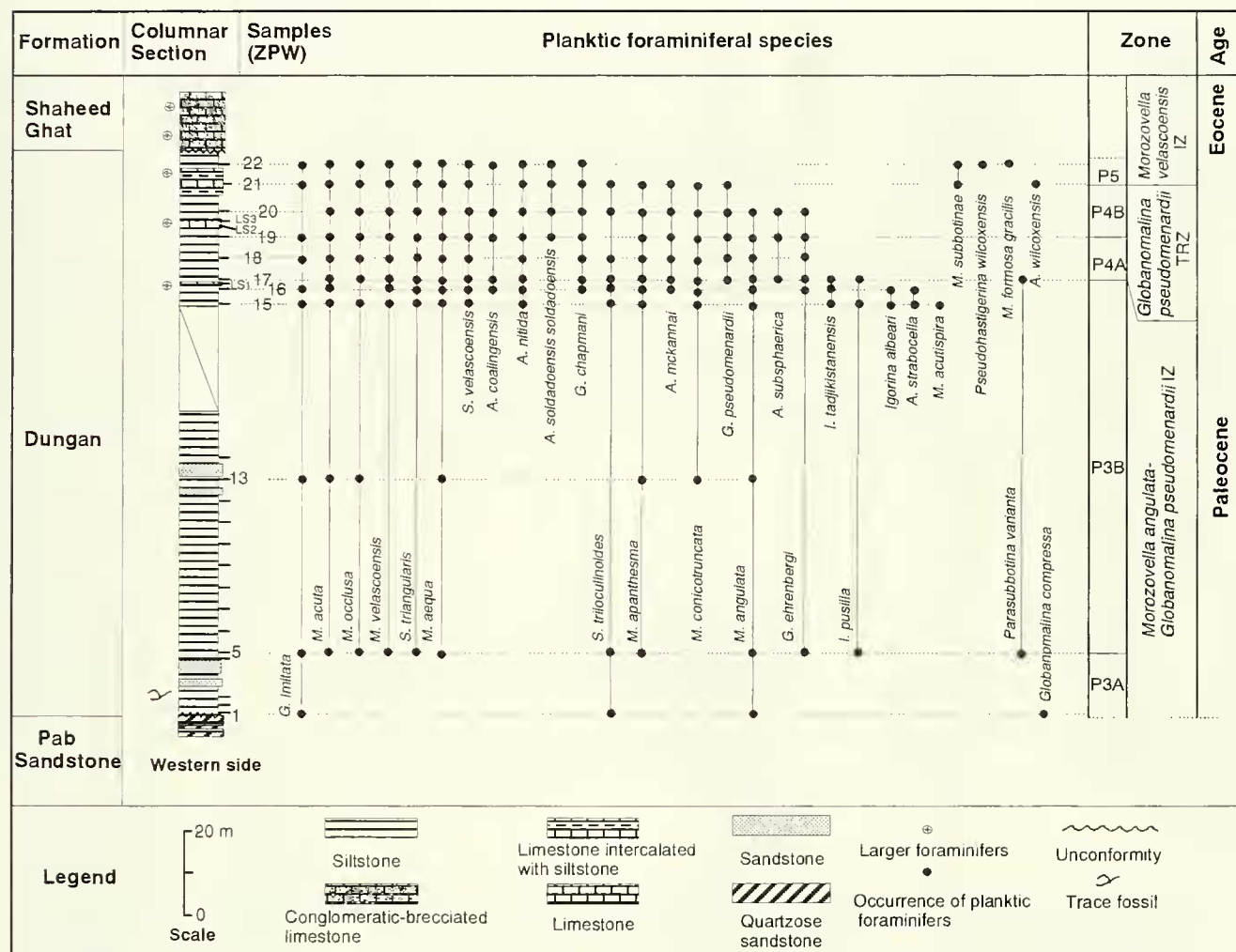


Figure 4. Measured columnar section along the western limb of the Zinda Pir Anticline showing lithostratigraphic sequences, sample locations and biostratigraphic distribution of the recovered planktic foraminifers. The numbers indicate the samples containing planktic foraminifers.

Paleocene Zones of the Dungan Formation

P3. *Morozovella angulata*/*Globanomalina pseudomenardii* Interval Zone

Zone P3 of Berggren and Norris (1997) and Olsson *et al.* (1999) is defined as the interval zone between the first appearance datum (FAD) of *Morozovella angulata* and the FAD of *Globanomalina pseudomenardii*. They also have subdivided Zone P3 into Subzones P3a and P3b using the FAD of *Igorina albeari*. In this paper, however, we cannot use their subzones because of the sporadic occurrence of *I. albeari* (Figures 3–5). Instead, we defined two regional subzones as described below, using the FAD of *M. acuta*.

P3A. *Morozovella angulata* -*M. acuta* Interval Subzone

Definition.—The lower boundary of this zone is not defined because of the missing sequence in the Zinda Pir and nonoccurrence of any planktic foraminifers in the Rakhi

Nala. The upper boundary is placed at the FAD of *Morozovella acuta* (Figure 4).

Occurrence.—This subzone is found restrictedly in the western section of the Zinda Pir Anticline (Figures 1, 4). Planktic foraminifers in this zone are not abundant, with the total number of specimens per sample ranging from 20 to 76 per sample. The rare occurrence of *M. angulata* is observed in Sample ZPW-1, associated with *Globanomalina imitata*, *G. compressa*, and *Subbotina triloculinoides*.

Correlation and age.—The FAD of *M. acuta* is a reliable datum in the tropical regions, being placed within Subzone P3b of Berggren and Norris (1997) and within the *Planorotalites pusilla pusilla* Zone of Toumarkine and Luterbacher (1985). The other index species of the Dungan Formation is *G. compressa*, which disappears within Zone P3a of Berggren and Norris (1997). The absence of *M. acuta* and cooccurrence of *M. angulata* and *G. compressa*

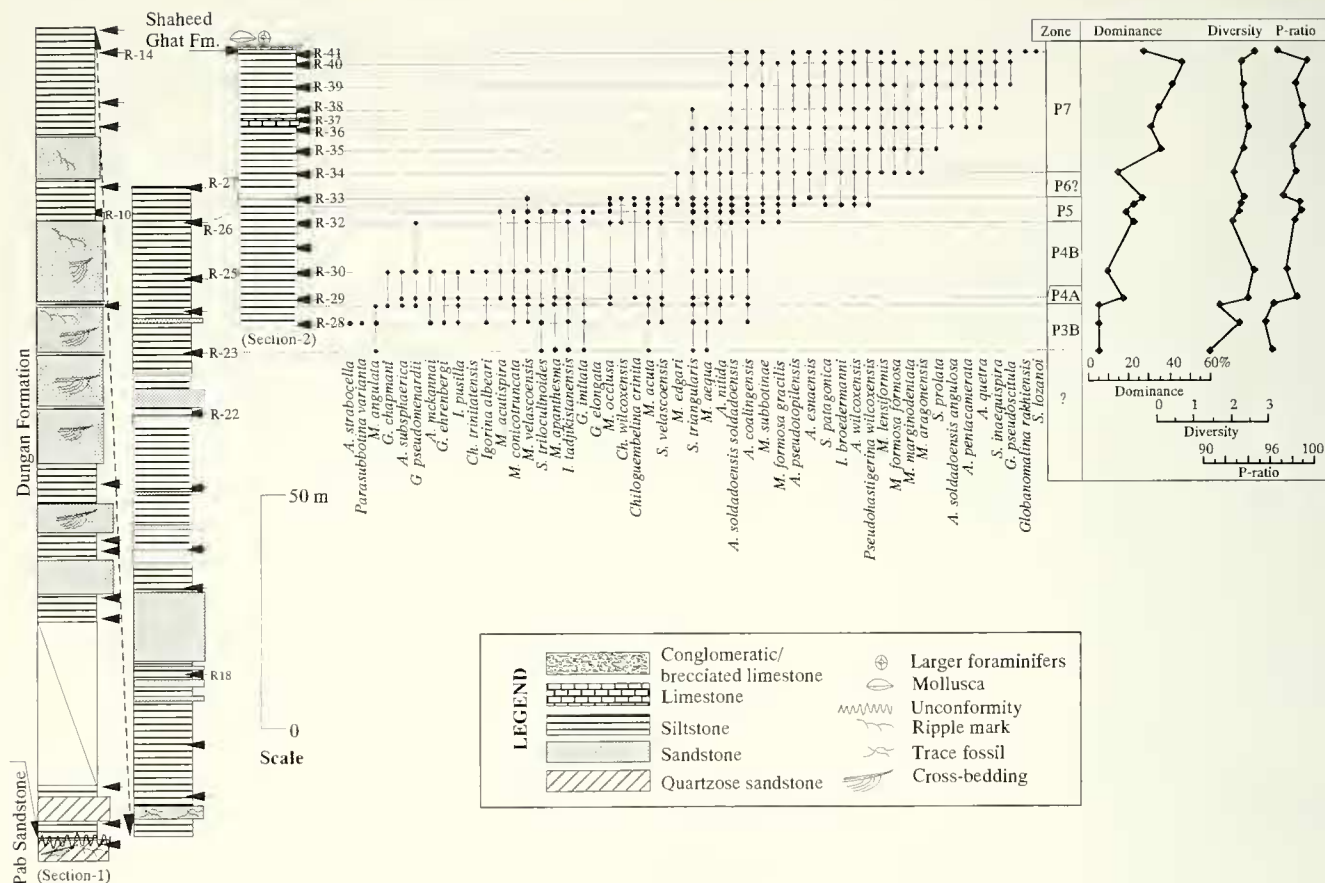


Figure 5. Measured columnar section along the Rakhi Nala (river) showing lithostratigraphic sequences, sample locations and biostratigraphic distribution of the recovered planktic foraminifers. The numbers indicate the samples containing planktic foraminifers. In addition, the results of quantitative analysis consisting of dominance (the most abundant species), diversity and the P-ratio are shown in this figure.

indicate that Subzone P3A corresponds to the interval from Subzone P3a to the lower part of Subzone P3b of Berggren and Norris (1997) (Figure 7). Hence, the age of Subzone P3A is assigned to the late Paleocene (Selendian).

P3B. *Morozovella acuta*-*Globanomalina pseudomenardii* Interval Subzone

Definition.—The interval of this zone ranges from the FAD of *M. acuta* to the FAD of the *Globanomalina pseudomenardii*.

Occurrence.—This subzone is observed in the interval from Samples ZPW-5 to ZPW-16 in the western section of the Zinda Pir Anticline and from Samples R23 to R28 in the Rakhi Nala (Figures 4, 5).

Correlation and age.—The dominant faunas of this subzone are *Morozovella* forms (*acuta*, *apantesma*, *occlusa*, and *velascoensis*). These species and another three species (*Globanomalina ehrenbergi*, *Igorina pusilla*, and *Subbotina triangularis*) appear first in Sample ZPW-5 of the Zinda Pir west section and R23 of the Rakhi Nala. This

subzone is correlated with the upper part of Subzone P3b of Berggren and Norris (1997), Olsson et al. (1999), and with the *P. pusilla pusilla* Zone of Toumarkine and Luterbacher, 1985 (Figure 7). The age of this zone is late Paleocene (Selendian).

P4. *Globanomalina pseudomenardii* Total Range Zone

The total range of *Globanomalina pseudomenardii* (Zone P4) is recognized as an excellent stratigraphic marker in many tropical regions (e.g. Bolli and Krasheninnikov, 1977; Toumarkine and Luterbacher, 1985). In the studied sections, the FAD of *Globanomalina pseudomenardii* has been placed at Sample ZPW-15 in the western section of the Zinda Pir Anticline, and at Sample R25 from the Rakhi Nala (Figures 4, 5). The last appearance datum (LAD) of *G. pseudomenardii* was observed in all three sections. Samples ZPE-20, ZPW-21 of the Zinda Pir Anticline and Sample R32 of the Rakhi Nala show the LAD of *G. pseudomenardii*. Some 25 species belonging to five genera were identified in this zone.

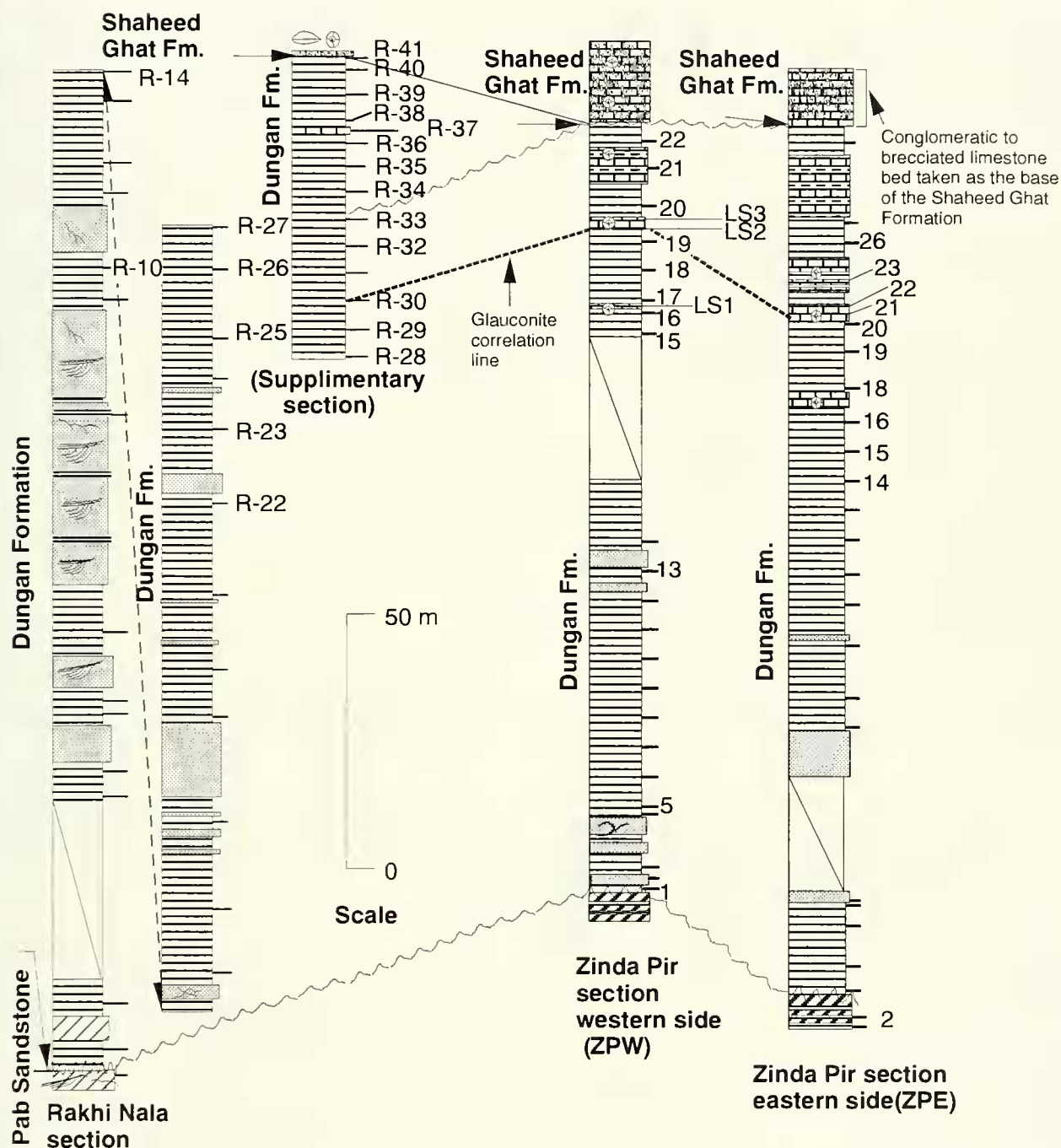


Figure 6. Lithostratigraphic and biostratigraphic correlation between measured columnar sections from the Rakhi Nala and the Zinda Pir area. The numbers indicate the samples containing planktic foraminifers.

Berggren and Norris (1997) have used the FADs of *Acarinina subsphaerica* and *A. soldadoensis soldadoensis* to subdivide their Zone P4 into three subzones (P4a, P4b and P4c). We cannot apply their definition in this area, because the stratigraphic ranges of both *A. subsphaerica* and

A. soldadoensis soldadoensis overlap in the Zinda Pir west section and in the Rakhi Nala (Figures 3–5). Olsson *et al.* (1999) has demonstrated that the stratigraphic range of *Acarinina subsphaerica* may extend upwards, close to Zone P4/P5 boundary. Therefore, we used only the FAD of *A.*

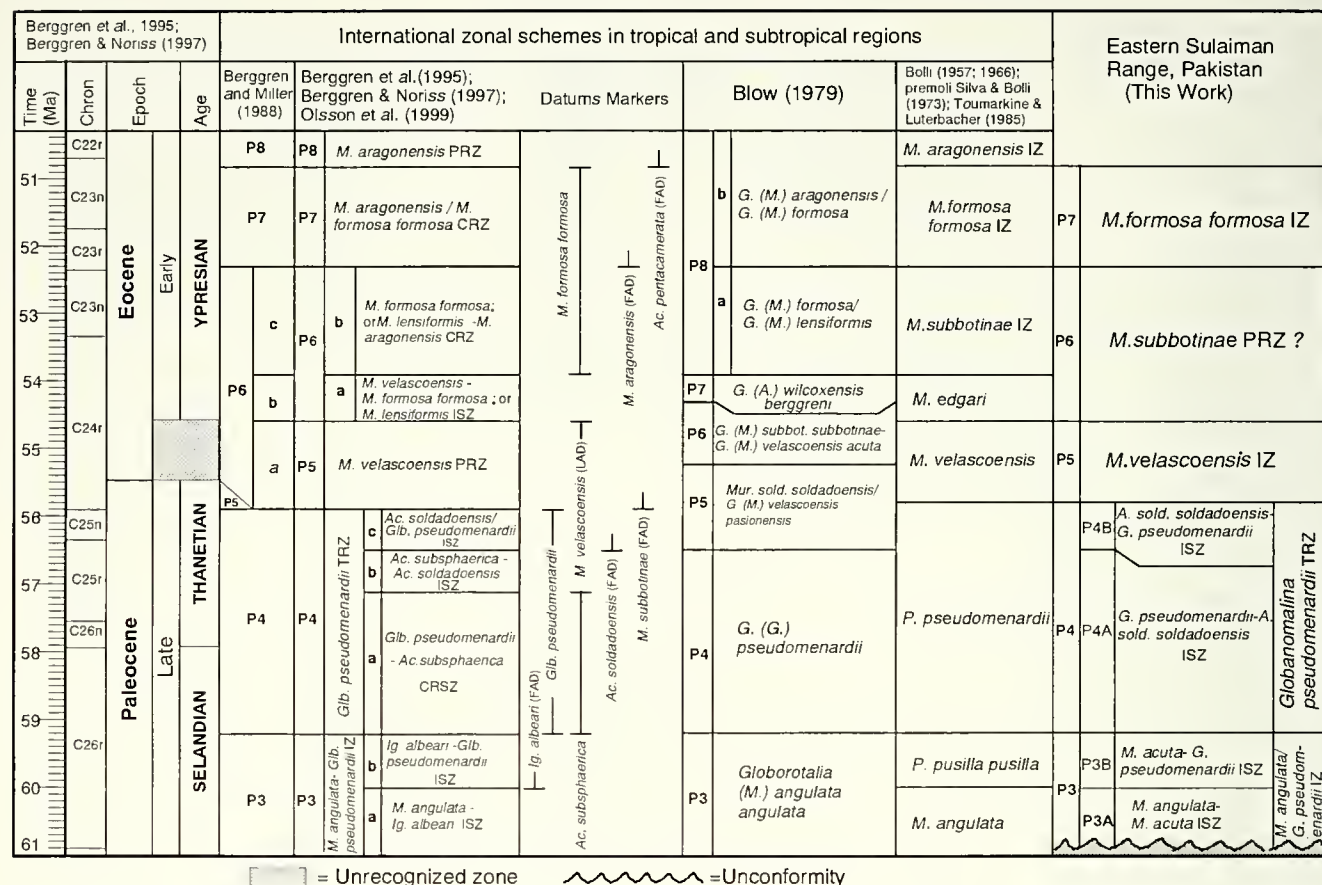


Figure 7. Correlation of planktic foraminiferal zones of the studied area with international low latitude zones. Here IZ: Interval Zone, TRZ: Total Range Zone, PRZ: Partial Range Zone, CRSZ: Concurrent Range Subzone, ISZ: Interval Subzone. A; Ac: *Acarinina*, Glb; G: *Globanomalina*, Ig; I: *Igorina*, M: *Morozovella*, P: *Planorotalites*, S: *Subbotina*. Age and epoch boundaries are adopted from Berggren et al. (1995) and Berggren and Norris (1997).

soldadoensis soldadoensis as an index marker, and subdivided Zone P4 into two subzones P4A and P4B as follows (Figure 7).

P4A. *Globanomalina pseudomenardii*-*Acarinina soldadoensis soldadoensis* Interval Subzone

Definition.—This subzone is defined as the interval zone between the FAD of *G. pseudomenardii* and the FAD of *A. soldadoensis soldadoensis*.

Occurrence.—This subzone is recognized in both sides of the Zinda Pir Anticline (Samples ZPE-14 to 15 in the east and ZPW-17 to 18 in the west) and in the Rakhi Nala (Samples R25 to R29).

Correlation and age.—The FAD of *A. soldadoensis soldadoensis* is one of the distinctive bioevents in the late Paleocene and is placed at Zones P4a/P4b boundary by Berggren and Norris (1997) and Olsson et al. (1999) or within the *Planorotalites pseudomenardii* (= *Globorotalia pseudomenardii*) Zone by Toumarkine and Luterbacher (1985). This subzone corresponds to the joint interval of

P4a and P4b (Figure 7) of Berggren and Norris (1997), and Olsson et al. (1999). The age span of this zone is late Paleocene, from the latest Selandian to early Thanetian. In the Dungan Formation, two species of *Igorina* (*albeari*, *pusilla*) and *Parasubbotina varianta* disappear within this subzone.

P4B. *Acarinina soldadoensis soldadoensis*/*Globanomalina pseudomenardii* Concurrent range Subzone

Definition.—Subzone is defined as the interval between the FAD of *A. soldadoensis soldadoensis* and the LAD of *G. pseudomenardii*.

Occurrence.—This subzone ranges from Samples ZPE-15 to 20 in the east section of the Zinda Pir Anticline, ZPW-19 to 21 in the west section of the Zinda Pir Anticline, and R29 to R32 in the Rakhi Nala (Figures 3–5).

Correlation and age.—This subzone is equivalent to Subzone P4c of Berggren and Norris (1997) and Olsson et al. (1999). The age of this subzone is late Paleocene (Thanetian). In the Dungan Formation, *Morozovella*

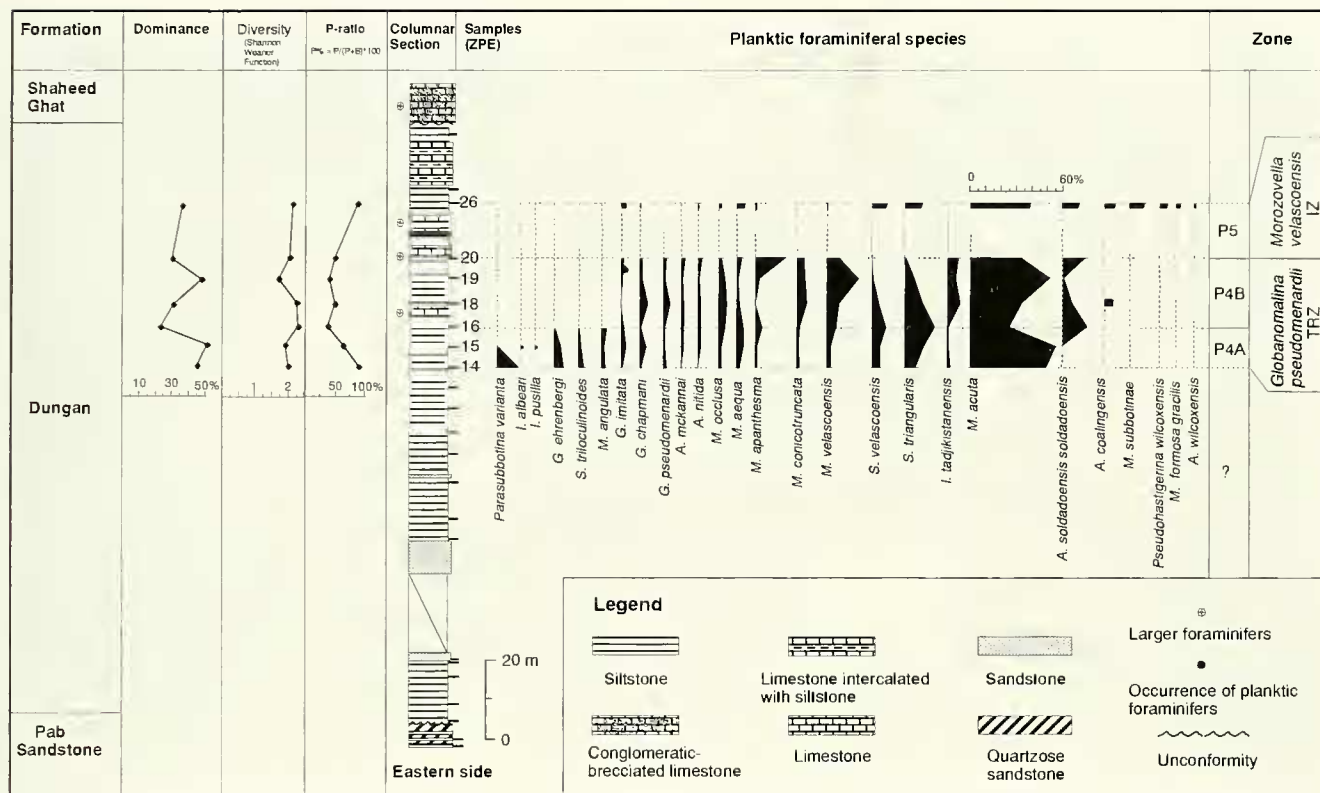


Figure 8. Results of the quantitative analysis of dominance (the most abundant species), diversity, P-ratio and the relative abundances of the characteristic planktic foraminiferal species along the eastern limb of the Zinda Pir Anticline. The numbers indicate the samples containing planktic foraminifers.

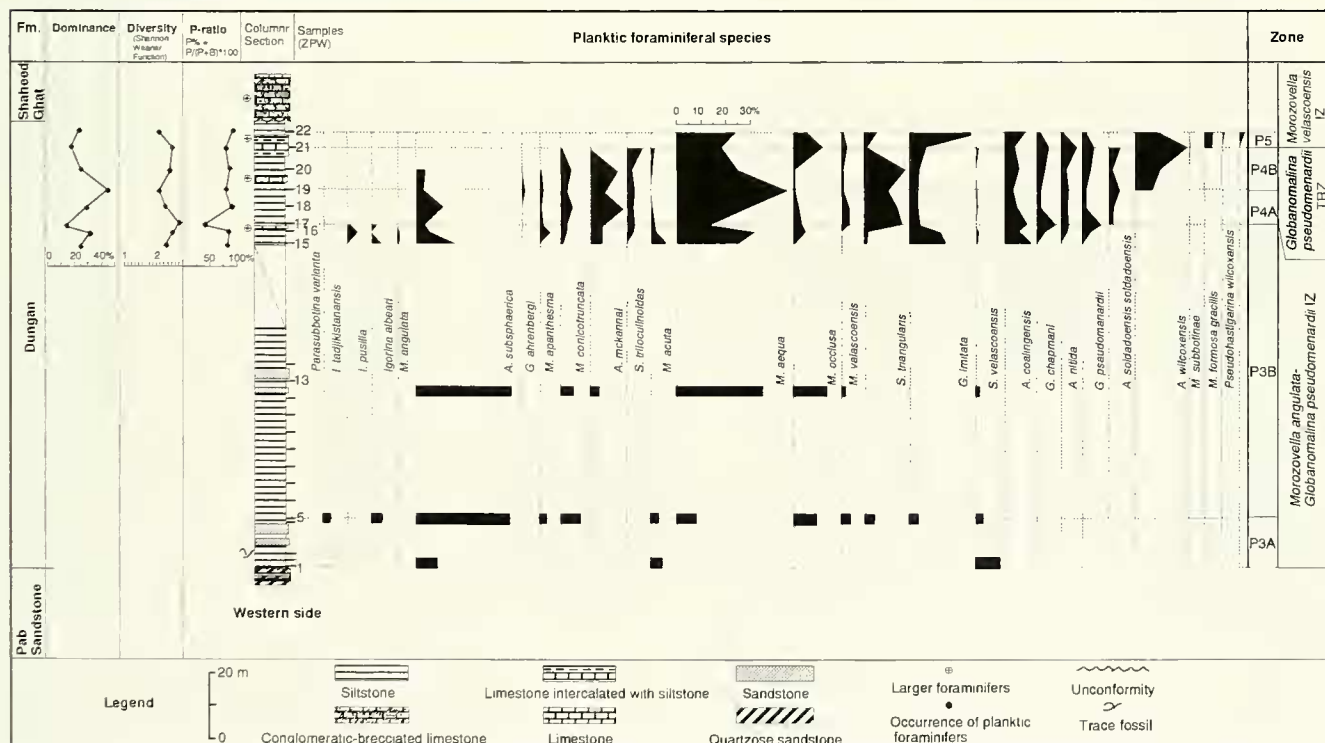


Figure 9. Results of the quantitative analysis of dominance, diversity, P-ratio and relative abundances of the most abundant characteristic planktic foraminiferal species along the western limb of the Zinda Pir Anticline. The numbers indicate the samples containing planktic foraminifers.

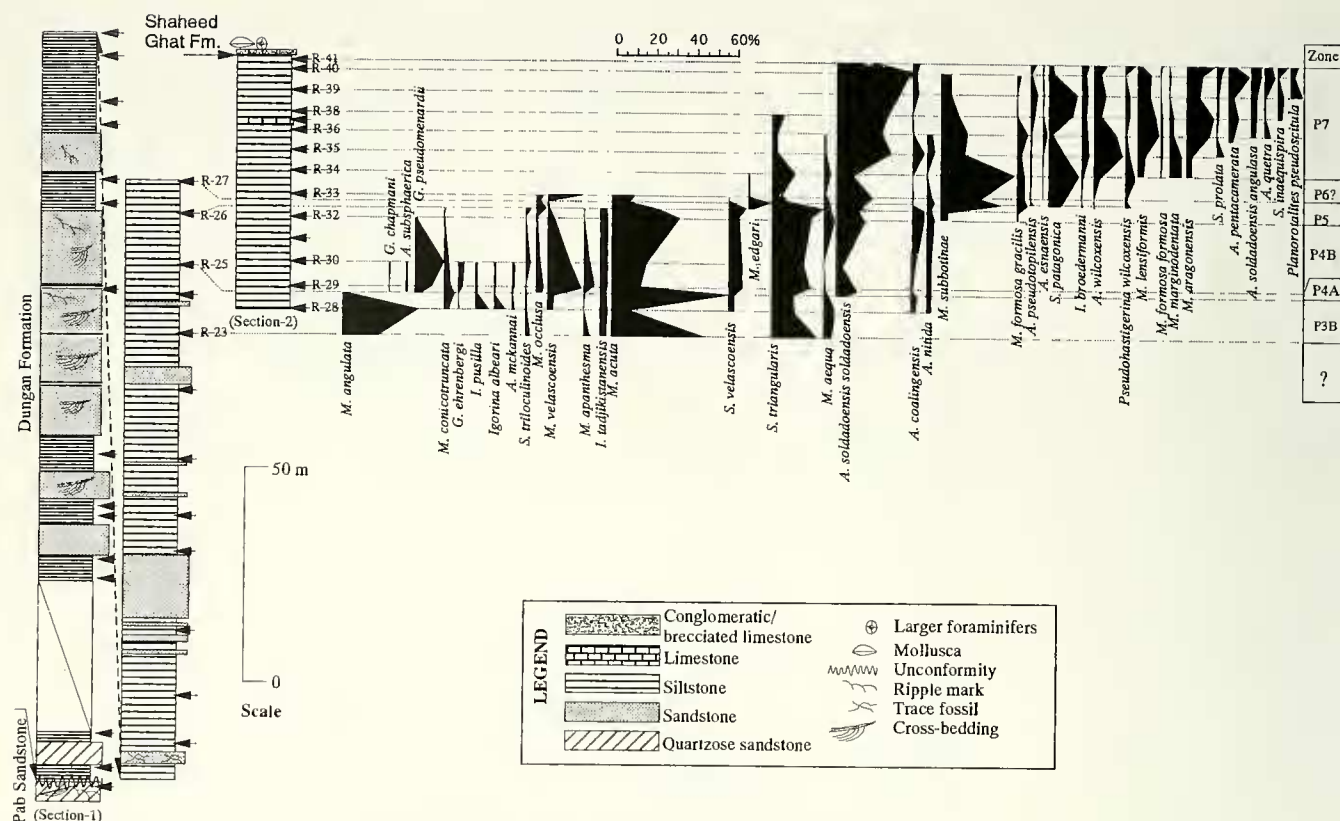


Figure 10. Results of the quantitative analysis of the relative abundances of the most abundant characteristic planktic foraminiferal species from the Rakhi Nala section. The numbers indicate the samples containing planktic foraminifers. For quantitative results of dominance, diversity, and the P-ratio see Figure 5.

angulata and *Globanomalina ehrenbergi* disappear within Subzone P4B.

P5. *Morozovella velascoensis* Interval Zone

Definition.—The definition of Zone P5 is the interval zone between the LAD of *G. pseudomenardii* and the LAD of *Morozovella velascoensis* (e.g. Berggren and Norris, 1997). The base of this zone has been found in all three sections. The upper limit of this zone was placed at the level of Sample R26 in the Rakhi Nala, but its boundary is not clear in the Zinda Pir Anticline, because the hard siltstone of the uppermost part of the Dungan Formation contains no planktic foraminifers (Figures 3, 4).

Occurrence.—This zone ranges from Samples ZPE-20 to 26 in the east and from Samples ZPW-21 to 22 in the west of the Zinda Pir Anticline, and from Sample R32 to R33 in the Rakhi Nala.

Correlation and age.—This zone corresponds exactly to Zone P5 of Berggren and Norris (1997) and Olsson *et al.* (1999). The assemblages of planktic foraminifers in the Dungan Formation contain abundant index species of latest Paleocene to early Eocene age such as *Morozovella subbotinae*, *M. formosa gracilis*, *Acarinina wilcoxensis* and *Pseudohastigerina wilcoxensis*. In particular, the last species is a marker for recognizing the Paleocene/Eocene (P/E)

boundary, appearing first just above the P/E boundary (Berggren, 1969; Stainforth *et al.*, 1975; Berggren and Aubry, 1998). The FAD of this species has been recorded in Samples ZPW-21 and ZPE-26 in the Zinda Pir, and in Sample R27 in the Rakhi Nala.

The chemo- and biostratigraphic events of a negative excursion of $\delta^{13}\text{C}$ (CIE) and the benthic foraminiferal extinction event (BEE) are used as the P/E boundary markers by many workers (e.g. Berggren and Aubry, 1998; Berggren *et al.*, 1998). The BEE in the investigated area is recognized between Samples R32 and R33 of the Rakhi Nala section (personal communication by Ritsuo Nomura, Shimane University, Japan). Hence, the P/E boundary can be placed between Samples R27 and R26 in the Rakhi Nala section. The P/E boundary in the Zinda Pir sections can be drawn tentatively between the Samples ZPE-20 and 26 in the east and ZPW-21 and 22 in the west, respectively. The age of this zone ranges from the latest Paleocene to earliest Eocene.

Eocene Zones of the Dungan Formation

In the study area, the siltstone sequence of the Dungan Formation is overlain by the conglomeratic to brecciated limestone beds present in the basal part of the Shaheed Ghat Formation. This field observation implies an

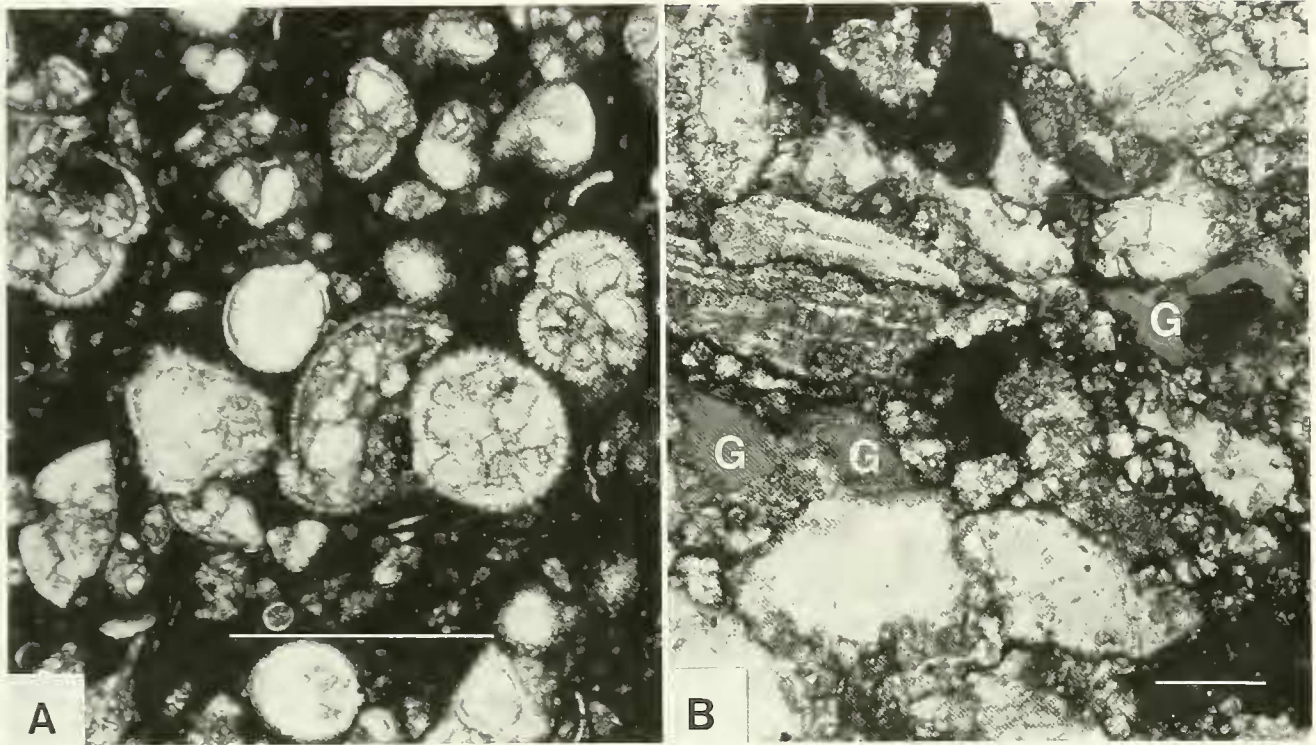


Figure 11. **A.** Pelagic limestone (wackestone) containing abundant planktic foraminifers from the Rakhi Nala section, Sample R37 (scale bar = 0.5mm). **B.** Limestone (wackestone) showing squashed (compacted) larger foraminifers and glauconitic grains from the Zinda Pir western section, Sample LS3 (scale bar = 0.5mm). G stands for glauconite grain.

unconformable relationship between the two formations. The biostratigraphic data from the Dungan Formation supports this interpretation because the age of the siltstone beds in the uppermost part of the Dungan Formation in the Zinda Pir sections is latest Paleocene to earliest Eocene (Zone P5), whereas such beds in the Rakhi Nala section are early Eocene in age (Zone P7). Two early Eocene zones described here are recognized from the Rakhi Nala section.

P6. *Morozovella subbotinae* Partial Range Zone

Definition.—This zone is defined as an interval zone between the LAD of *M. velascoensis* and the FAD of *M. aragonensis*.

Occurrence.—None occurred in the intervening samples between the Sample R27 and the Sample R34 in the study area.

P7. *Morozovella aragonensis*/*M. formosa formosa* Concurrent-Range Zone

Definition.—This zone is defined by the interval from the FAD of *M. aragonensis* to the LAD of *Morozovella formosa formosa*. The upper boundary of this zone probably lies within the overlying Shaheed Ghat Formation.

Occurrence.—The interval of this zone is recognized between the Samples R34 and R41 that include many early Eocene species such as *Morozovella aragonensis*, *M.*

formosa formosa, *Subbotina inaequispira*, and *S. lozanoi*. Two species (*Acarinina nitida* and *Morozovella aequa*) disappear close to the top of this interval (Figure 5).

Correlation and age.—Zone P7 of Blow (1969, 1979) has been revised by Berggren and Miller (1988), who used the FAD of *M. aragonensis* as the lower boundary of this zone and the LAD of *M. formosa formosa* as the top. This zone corresponds to the joint interval of the *M. formosa formosa* Zone and the lower part of the *Acarinina pentacamerata* Zone of Toumarkine and Luterbacher (1985). The age of this zone is early Eocene (middle to late Ypresian).

Quantitative analysis of planktic assemblages

For calculation of quantitative indices (plankton ratio, dominance and species diversity), we used the samples containing over 100 individuals. In the Rakhi Nala, all samples from Zone P3 to P7 yielded abundant and well-preserved foraminifers (Appendix 2). However, the total number per samples of individuals recovered from Zone P3 of the Zinda Pir sections amounted to less than 100. The number of specimens in the other samples in the Zinda Pir exceeded 200 individuals per sample.

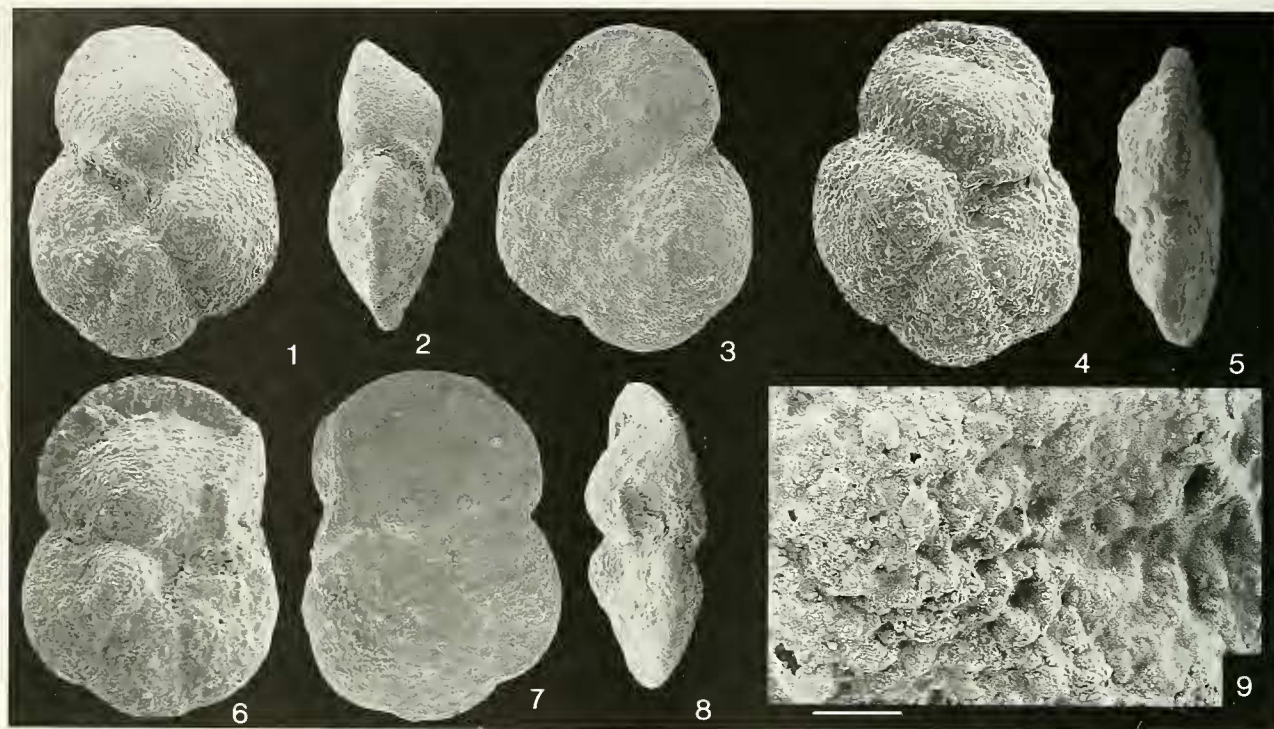


Figure 12. *Globanomalina rakhiensis* sp. nov. 1–3: Holotype, (IGUT coll. cat. no. 50101) umbilical, side and spiral views, Sample R41, all $\times 270$. 4, 5: Paratype, (IGUT coll. cat. no. 50102), umbilical and side views, Sample R41, all $\times 330$. 6–8: Paratype, (IGUT coll. cat. no. 50103) side, spiral and umbilical views. This specimen has more compressed peripheral margin on umbilical side, more limbate intercameral sutures on spiral side and more developed keel in side view, Sample R41, all $\times 300$. 9: An enlarged view of specimen (as illustrated in Figure 4) shows smooth wall surface with some pustules (scale bar = $10\mu\text{m}$)

Results and discussion

1. Plankton-ratio

The plankton-ratio (P-ratio) is expressed by the following formula:

$$\text{P-ratio} = [P/(P+B)] \times 100$$

Here P and B represent the number of specimens of planktic and benthic foraminifers, respectively. The trend of P-ratios differs between the eastern and western sections of the Zinda Pir Anticline (Figures 8, 9). In the east, the P-ratios of Zone P4A are as high as 90%, decreasing gradually to a minimum (39%) in Zone P4B, and then recovering to 89% in Zone P5. In the west, the P-ratios are consistently high (80–90%) during Zones P3B to P5, except for a figure of 31% in Sample ZPW-17 in the lowermost part of Zone P4A. In the Rakhi Nala section, the P-ratios of all samples show high values of more than 95% (Figure 5).

2. Species compositions

The morozovellid species are common to abundant throughout the studied sequences, exceeding about 30–40% of the total number of specimens (Figures 8–10). The dominant morozovellids are *M. angulata* in Zone P3B, *M. acuta* and *M. velascoensis* in Zone P4 and three species (*M.*

acuta, *M. subbotinae*, and *M. aequa*) in Zone P5 in the Zinda Pir area. In the Rakhi Nala region, the assemblage of Zone P3B is dominated by *M. acuta* and *M. angulata* (40–60%), whereas that of Zones P4 and P5 is dominated by *M. acuta*, *M. conicotruncata*, *M. occlusa*, and *M. velascoensis* (30–35%). The relative abundance of *Acarinina* and *Subbotina* during Zones P3 to P5 is relatively high, fluctuating between 10 and 20% of the total for each genus. Those of the other genera (*Igorina*, *Globanomalina*, and *Parasubbotina*) are less than 10% for each genus.

The replacement of the Paleocene morozovellid group (*M. velascoensis*, *M. angulata*, *M. conicotruncata* and *M. apantesma*) by early Eocene forms (*M. formosa gracilis*, *M. formosa formosa*, *M. lensiformis*, *M. subbotinae*, *M. marginodentata* and *M. edgari*) occurred during Zones P5 to P6 (Figure 5). The acarininids (*A. pentacamerata*, *A. soldadoensis soldadoensis*, *A. wilcoxensis*) and subbotinids (*S. patagonica*, *S. inaequispira*, *S. prolata*) increased within Zone P7, accompanied by a decrease in the abundances of the morozovellid forms (Figure 10). This increase in the abundance of acarininid and subbotinid forms is probably related to a temperature decrease after the Paleocene-Eocene boundary. In the late Paleocene, the period spanning latest zone P4 to P5 is of maximum warmth (LPTM), with Zones

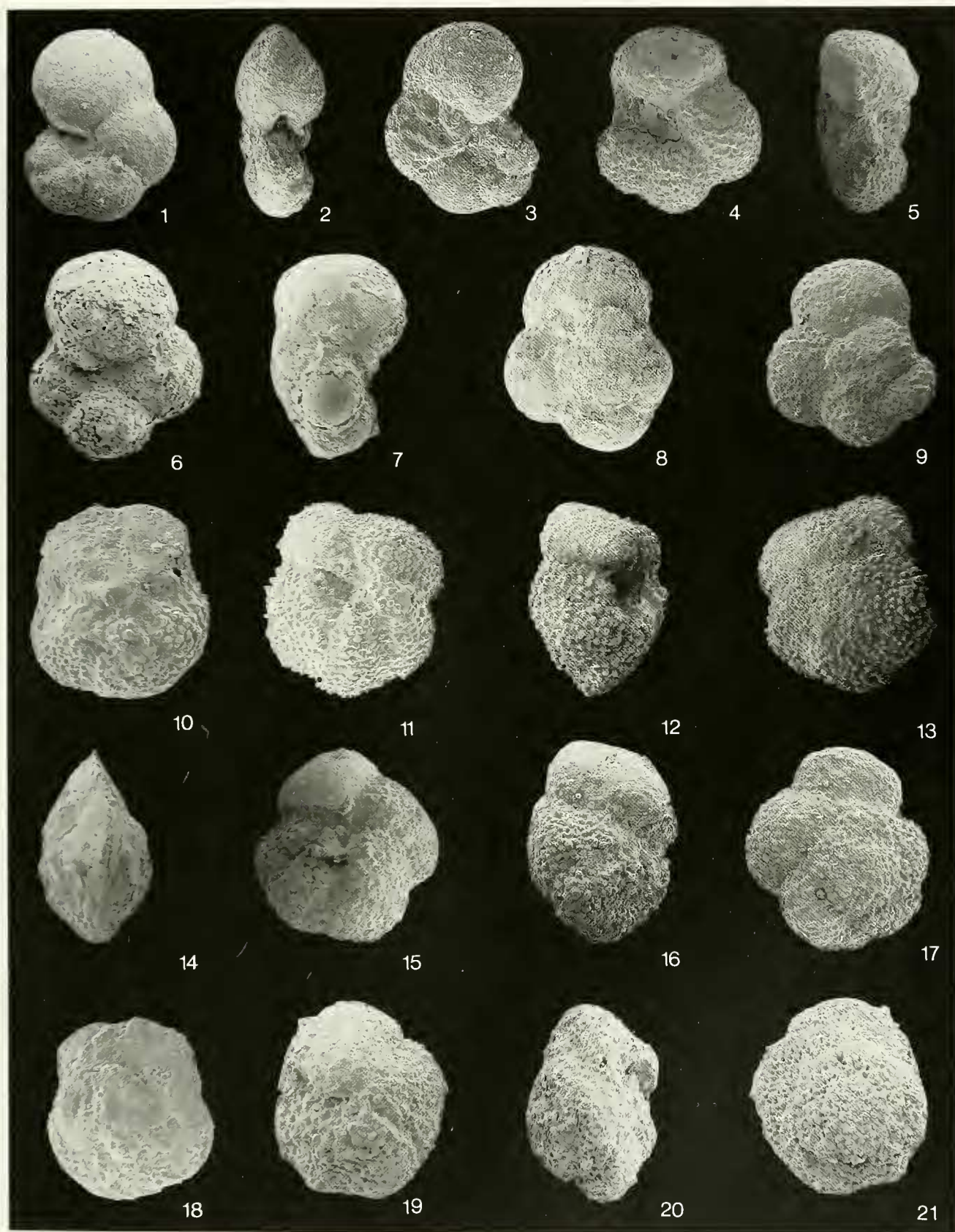


Figure 13.

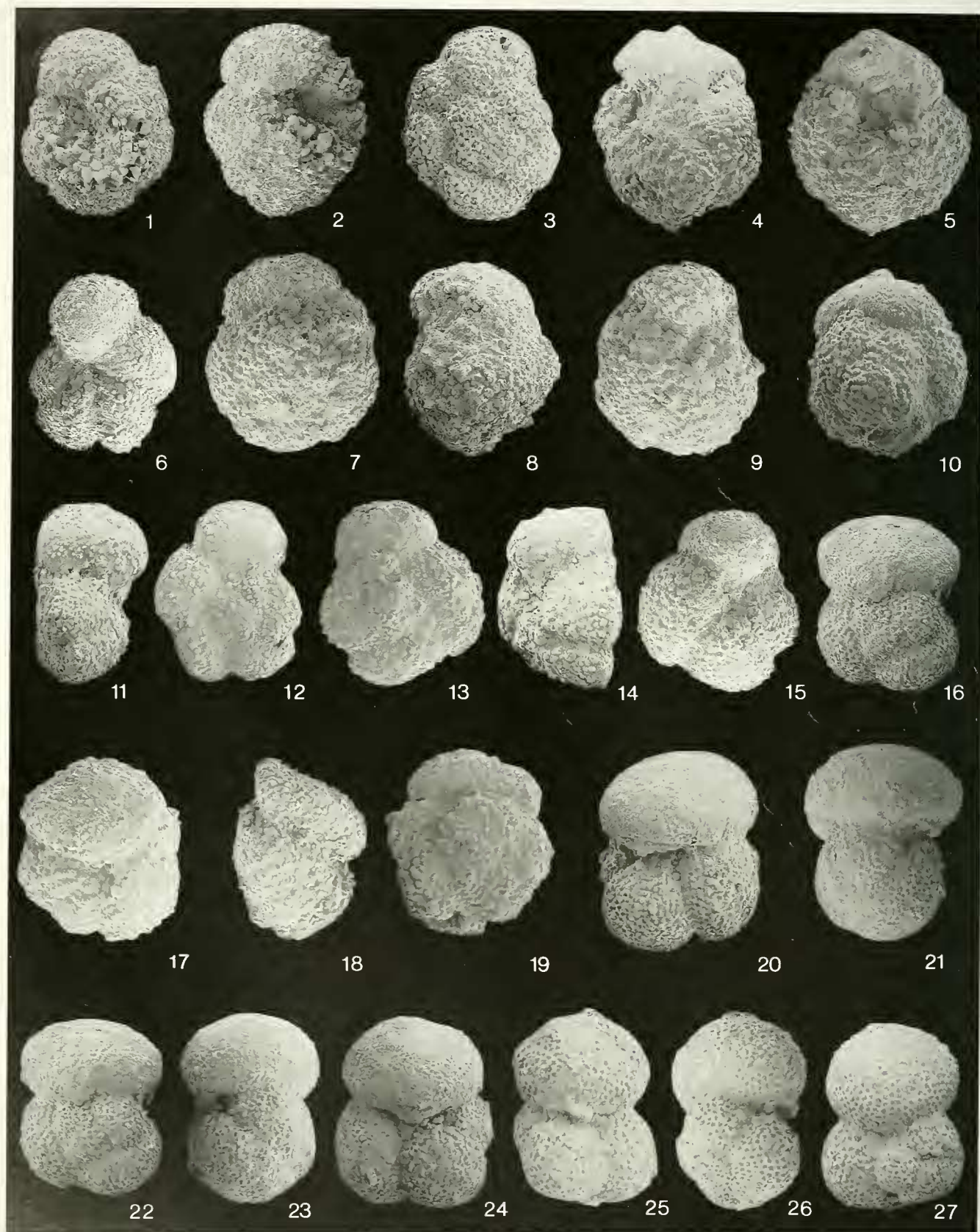


Figure 14.

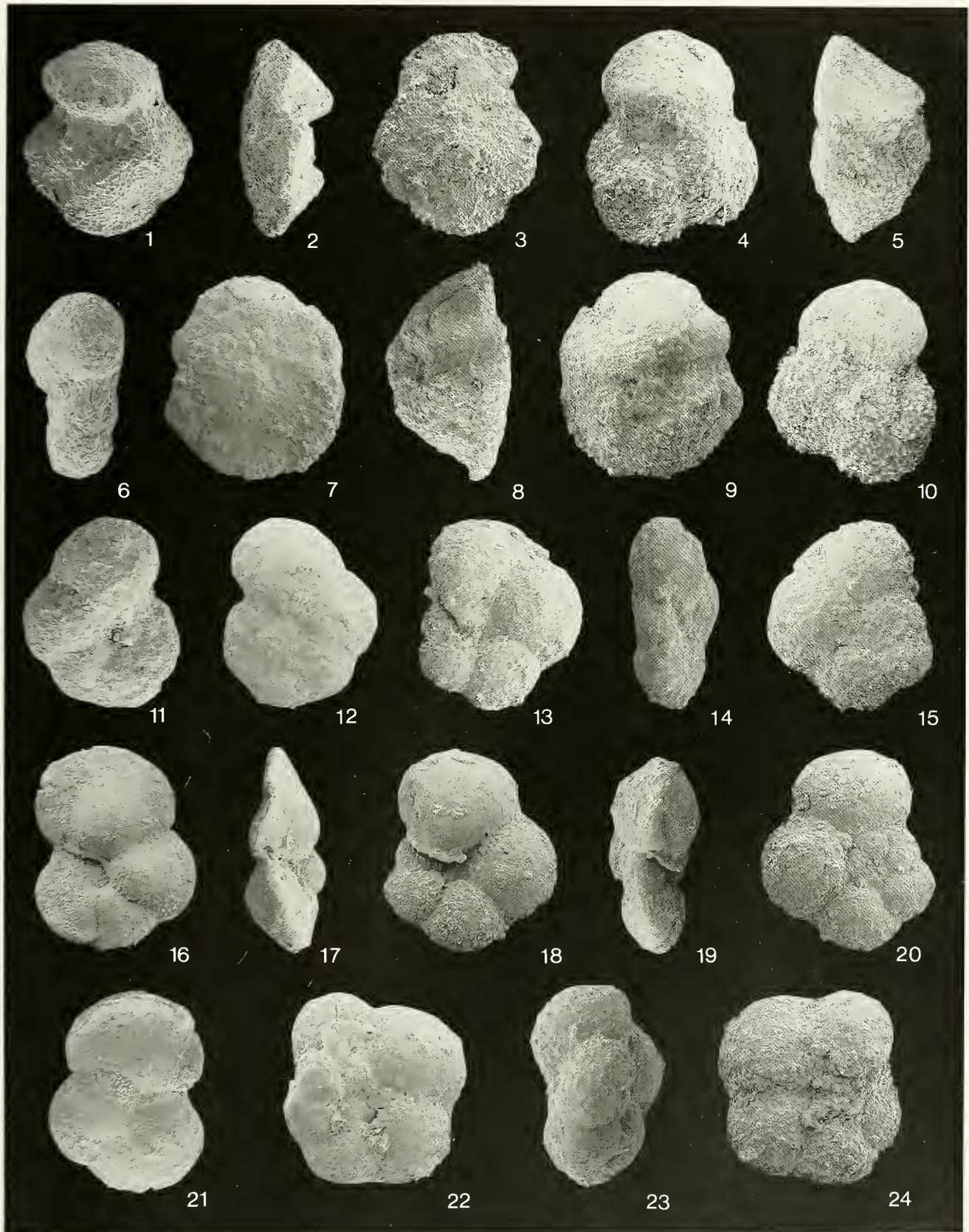


Figure 15.

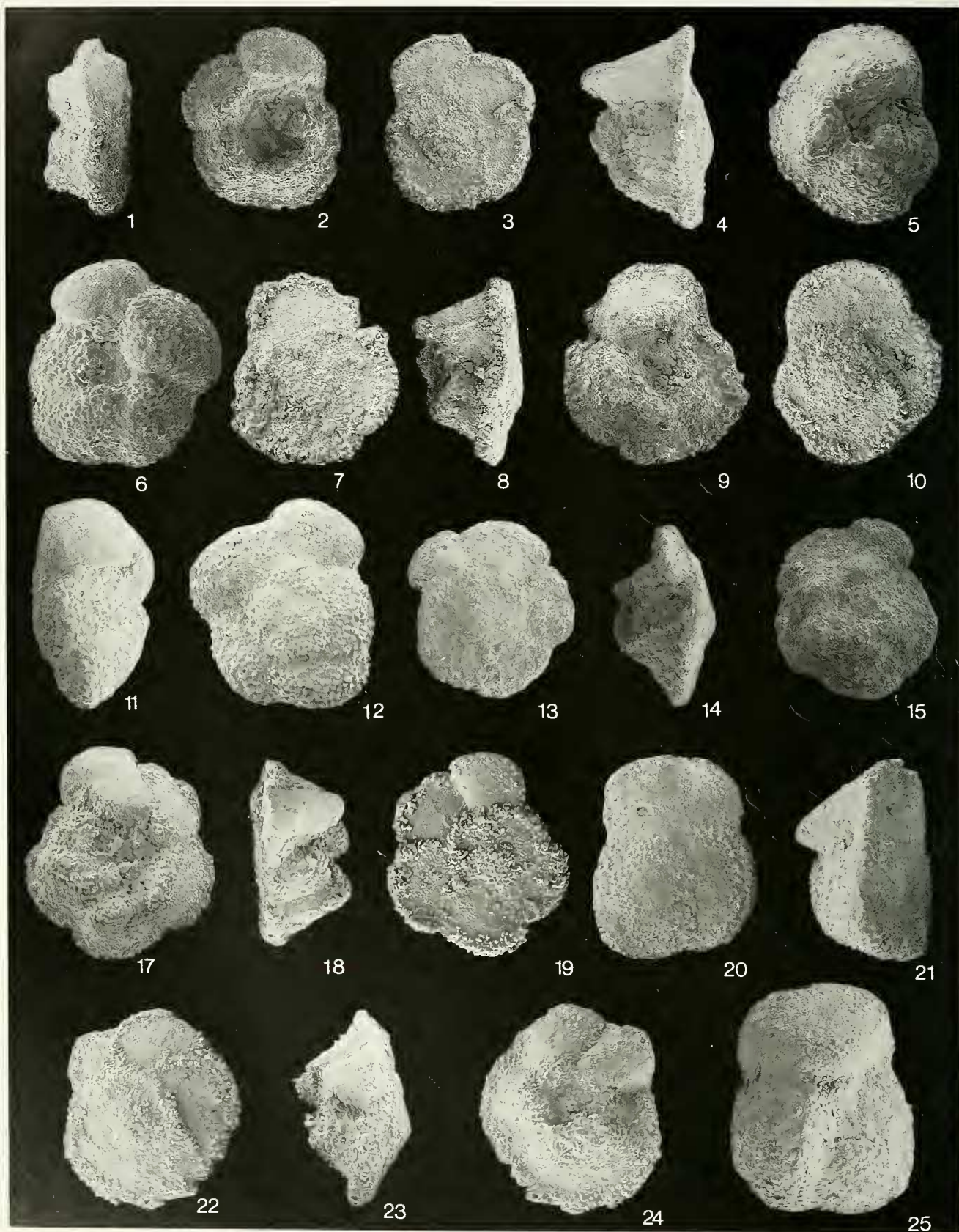


Figure 16.

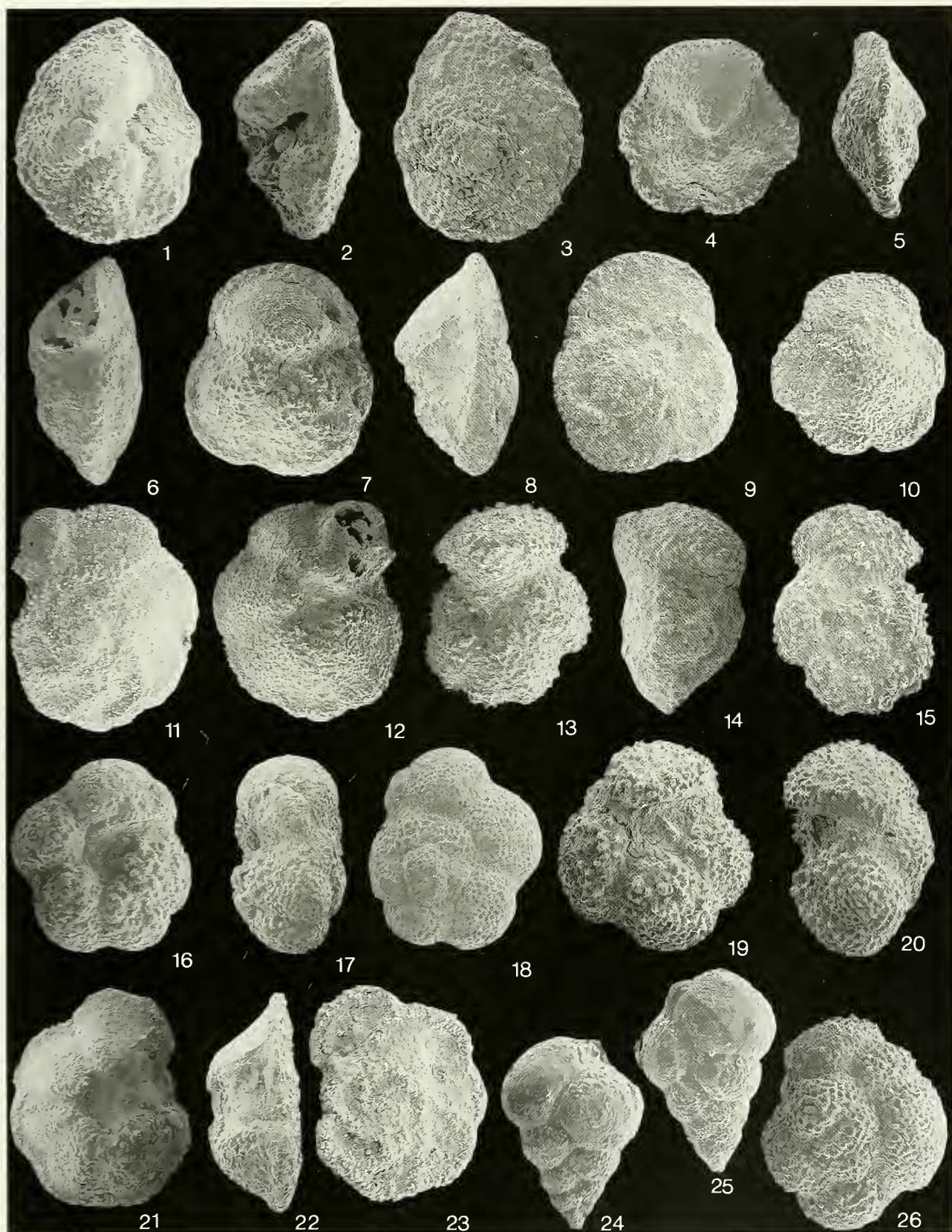


Figure 17.

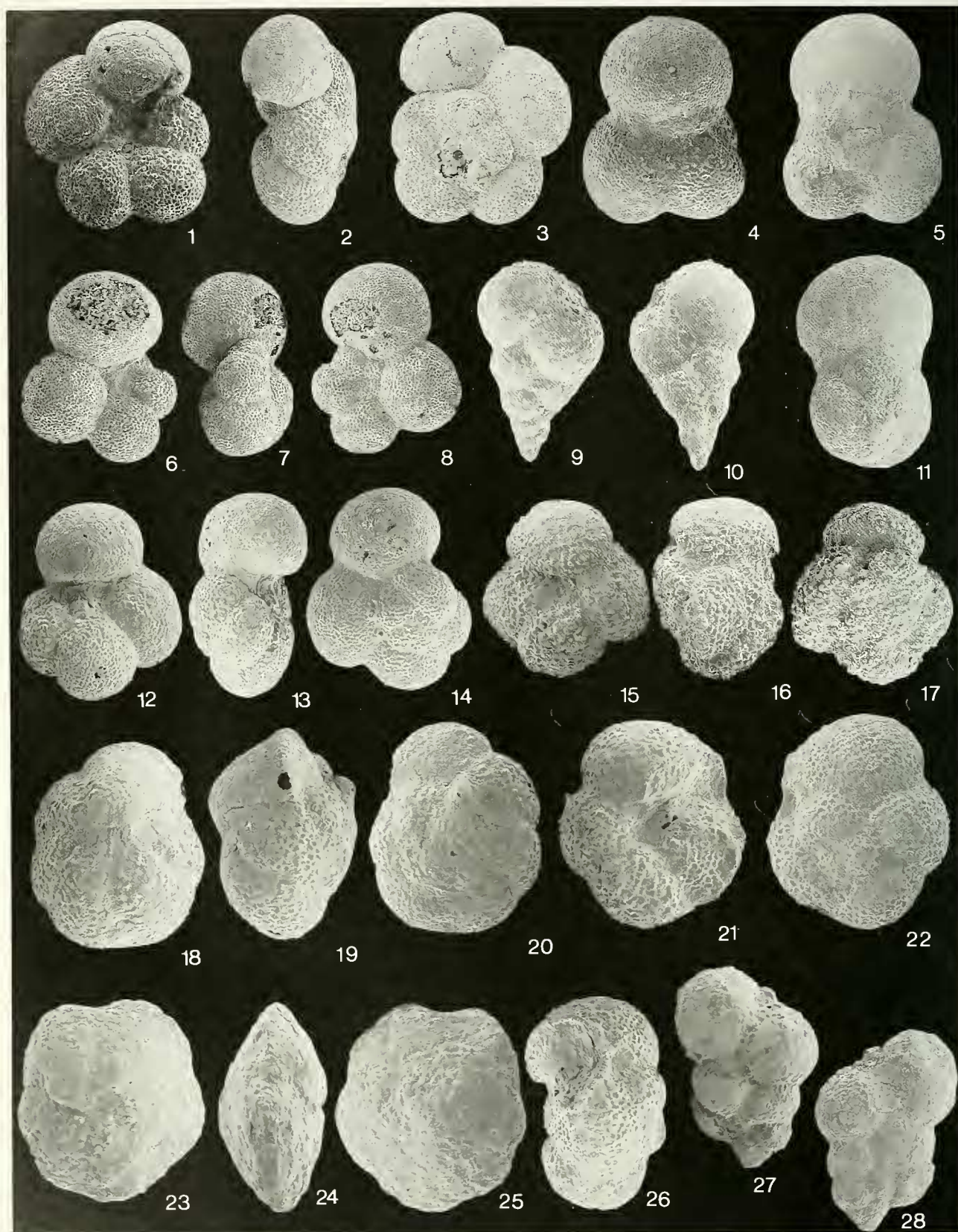


Figure 18.

P6b and P7 becoming slightly cooler (e.g., Stott *et al.*, 1990; Bralower *et al.*, 1995). This cooling event is probably responsible for the increase in percentage of *Acarinina* and *Subbotina* species in Zone P7.

3. Diversity and dominance trends

We calculated the species diversity in both sections of the Zinda Pir (Zones P3B to P5) and in the Rakhi Nala section (Zones P3 to P7) using the Shannon-Wiener Function by the following mathematical expression.

$$H(S) = -\sum_{i=1}^S p_i \ln p_i \text{ (from } i = 1 \text{ to } S)$$

Where p_i is the relative abundance of the i -th species in a

sample and S is the number of species. Dominance index is expressed as percentages of the most abundant species. The relationship between the Shannon-Wiener diversity index and dominance index display distinct opposite trends (Figures 8–10).

In the east of the Zinda Pir, the species richness decreases gradually from 20 to 15 species during Zones P4A to P5 (Appendix 2). The diversity index is, however, relatively constant (1.9 and 2.0), with generally lower values than in the western samples. The lowest value (15 species) was recorded from the earliest Eocene Sample ZPE-26, but this figure is not the overall minimum (Figure 8).

Figure 13. (p.287) 1–3. *Globanomalina chapmani* (Parr), umbilical, side and spiral views, Sample ZPW-17, all $\times 250$. 4, 5, 9. *Acarinina wilcoxensis* (Cushman and Ponton), umbilical, side and spiral views, Sample ZPW-21, all $\times 230$. 6–8. *Parasubbotina varianta* (Subbotina), umbilical, side and spiral views, Sample ZPW-5, all $\times 500$. 10, 14, 18. *Igorina albeari* (Cushman and Bermudez), umbilical, side and spiral views, Sample ZPW-15, all $\times 230$. 11–13. *Igorina tadjikistanensis* (Bykova), umbilical, side and spiral views, Sample ZPW-17, all $\times 220$. 15–17. *Acarinina strabocella* (Loeblich and Tappan), umbilical, side and spiral views, Sample ZPW-16, all $\times 230$. 19–21. *Igorina pusilla* (Bolli), umbilical, side and spiral views, Sample ZPW-17, all $\times 300$.

Figure 14. (p.288) 1–3. *Acarinina mckannai* (White), umbilical, side and spiral views, Sample ZPW-17, all $\times 180$. 4–5, 10. *Acarinina nitida* (Martin), side, umbilical and spiral views, Sample ZPW-20, all $\times 220$. 6, 11–12. *Acarinina soldadoensis soldadoensis* (Bronnimann), umbilical, side and spiral views, Sample ZPW-20, all $\times 170$. 13–15. *Acarinina soldadoensis soldadoensis* (Bronnimann) spiral, side and umbilical views, Sample ZPW-20, all $\times 200$. 7–9. *Acarinina subsphaerica* (Subbotina), spiral, side and umbilical views, Sample ZPW-19, all $\times 220$. 16, 20, 21. *Subbotina velascoensis* (Cushman), spiral, umbilical and side views, Sample ZPW-17, all $\times 200$. 17–19. *Acarinina coalingensis* (Cushman and Hanna), umbilical, side and spiral views, Sample ZPW-20, all $\times 200$. 22–24. *Subbotina triangularis* (White), spiral, side and umbilical views, Sample ZPW-17, all $\times 180$. 25–27. *Subbotina trilocolinoides* (Plummer), umbilical, side and spiral views, Sample ZPW-17, all $\times 300$.

Figure 15. (p.289) 1–3. *Morozovella angulata* (White), umbilical, side and spiral views, Sample ZPE-15, all $\times 150$. 4, 5, 10. *Morozovella subbotinae* (Morozova), umbilical, side and spiral views, Sample ZPE-26, all $\times 150$. 6, 11, 12. *Pseudohastigerina wilcoxensis* (Cushman and Ponton), apertural face, lateral views, Sample ZPW-22, all $\times 270$. 7–9. *Morozovella conicotruncata* (Subbotina), spiral, side and umbilical views, Sample ZPW-16, all $\times 200$. 13–15. *Globanomalina imitata* (Subbotina), umbilical, side and spiral views, Sample ZPW-18, all $\times 250$. 16, 17, 21. *Globanomalina pseudomenardii* (Bolli), umbilical, side and spiral views, Sample ZPW-17, all $\times 170$. 18–20. *Globanomalina ehrenbergi* (Bolli), umbilical, side and spiral views, Sample ZPW-17, all $\times 170$. 22–24. *Globanomalina imitata* (Subbotina), spiral, side and umbilical views, Sample ZPW-18, all $\times 200$.

Figure 16. (p.290) 1–3. *Morozovella acuta* (Toulmin), side, umbilical and spiral views, Sample ZPW-17, all $\times 100$. 4–5, 10. *Morozovella acuta* (Toulmin), side, umbilical and spiral views, Sample ZPW-19, all $\times 160$. 6, 11, 12. *Morozovella apantesma* (Loeblich and Tappan), umbilical, side and spiral views, Sample ZPW-21, all $\times 200$. 7–9. *Morozovella acutispira* (Bolli and Cita), spiral, side and umbilical views, Sample ZPW-15, all $\times 150$. 13–15. *Morozovella gracilis* (Bolli), spiral, side and umbilical views, Sample ZPE-26, all $\times 130$. 17–19. *Morozovella velascoensis* (Cushman), umbilical, side and spiral views, Sample ZPE-15, all $\times 140$. 20, 21, 25. *Morozovella aequa* (Cushman and Renz), spiral, side and umbilical views, Sample ZPW-21, all $\times 220$. 22–24. *Morozovella occlusa* (Loeblich and Tappan), spiral, side and umbilical views, Sample ZPW-15, all $\times 160$.

Figure 17. (p.291) 1–3. *Morozovella edgari* (Primoli Silva and Bolli), umbilical, side and spiral views, Sample R33, all $\times 270$. 4, 5, 10. *Morozovella marginodentata* (Subbotina), umbilical, side and spiral views, Sample R40, all $\times 200$. 6, 11, 12. *Morozovella aragonensis* (Nuttall), side, spiral and umbilical views, Sample R41, all $\times 130$. 7–9. *Morozovella lensiformis* (Subbotina), umbilical, side and spiral views, Sample R40, all $\times 170$. 13–15. *Acarinina quetra* (Bolli), umbilical, side and spiral views, Sample R41, all $\times 180$. 16–18. *Acarinina pentacamerata* (Subbotina), umbilical, side and spiral views, Sample R40, all $\times 150$. 19, 20, 26. *Acarinina soldadoensis angulosa* (Bolli), umbilical, side and spiral views, Sample R38, all $\times 200$. 21–23. *Morozovella formosa formosa* (Bolli), umbilical, side and spiral views, Sample R41, all $\times 130$. 24, 25. *Chiloguembelina trinitatensis* (Cushman and Renz), lateral views, Sample R30, all $\times 350$.

Figure 18. (p.292) 1–3. *Subbotina lozanoi* (Colom), umbilical, side and spiral views, Sample R41, all $\times 170$. 4, 5, 11. *Subbotina patagonica* (Todd and Knicker), umbilical, spiral and side views, Sample R38, all $\times 150$. 6–8. *Subbotina inaequispira* (Subbotina), umbilical, side and spiral views, Sample R41, all $\times 150$. 9–10. *Chiloguembelina crinita* (Glaessner), lateral views, Sample R30, all $\times 370$. 12–14. *Subbotina prolata* (Bolli), umbilical, side and spiral views, Sample R41, all $\times 170$. 15–17. *Acarinina pseudotopilensis* (Subbotina), umbilical, side and spiral views, Sample R39, all $\times 160$. 18–20. *Igorina broedermanni* (Cushman and Bermudez), umbilical, side and spiral views, Sample R41, all $\times 200$. 21, 22, 26. *Acarinina esnaensis* (LeRoy), umbilical, spiral and side views, Sample R41, all $\times 190$. 23–25. *Planorotalites pseudoscitula* (Glaessner), umbilical, side and spiral views, Sample R39, all $\times 450$. 27, 28. *Chiloguembelina wilcoxensis* (Cushman and Ponton), lateral views, Sample R33, all $\times 180$.

In the western section, the species richness during Zones P3B to P4 is consistently high (17 to 20 species), except for sample ZPW-18 (Zone P4A, 16 species) (Appendix 3). The species diversity fluctuates between 2.1 and 2.6. The minimal values of both richness (15 species) and diversity (2.1) are yielded by the earliest Eocene Sample ZPW-22 (Figure 9).

In the Rakhi Nala section, the species richness during the Paleocene (Zones P3B to P4) is high and nearly constant (19 to 22 species), excepting Sample R23 (8 species, Zone P3B). The diversity of two samples (Samples R23 and R25) of Zone P3B-P4 is about 1.6 but varies to 2.5 in Sample R30 (Zone P4B). The Eocene species richness during Zones P5 to P7 ranges from 16 to 20 species, and the diversity index is constant at close to 2.5 (Figure 10). The diversity during the earliest Eocene is consistently high (2.2–2.3), differing from the trends in the Zinda Pir.

4. Depositional environment

The sequence of the Dungan Formation is characterized by a remarkable change of lithology in the studied regions. During the late Paleocene (Zone P3), the strata of both regions (Zinda Pir and Rakhi Nala) consist of siltstone subordinate to sandstone. The interbeds of sandstone show the westward-thickening trend as sandstone beds are abundant and thick in the Rakhi Nala (Figure 6). In Zone P4, two basins were filled with siltstone, with rarely intercalating thin limestone beds containing larger foraminifers. After Zone P5, the limestones became thicker in the eastern section of the Zinda Pir, and the lithology changed from a siltstone-dominant facies to a limestone-dominant one in the eastern area. As a whole, limestone deposits thinned to the westward from the Zinda Pir to the Rakhi Nala, while siltstone deposition went on in the Rakhi Nala basin, located in the western region.

As a rule, plankton-ratios (P-ratios) increase from the shelf to the open-ocean environment, and exceed 50% in the deeper environment beyond the outer shelf in both modern and ancient sediments (e.g. Ingle, 1980; Gibson, 1989). The high P-ratios of all three sections of the Dungan Formation strongly indicate an open marine environment in the studied area. The highest P-ratios (98 to 99%), high values of species richness and diversity index in the Rakhi Nala suggest that the paleodepth of the Rakhi Nala basin was greater than that of the Zinda Pir. Furthermore, the planktic foraminiferal assemblage of the western section in the Zinda Pir Anticline also represents higher species richness and P-ratios than does that of the eastern one. Hence, the sedimentary basin of the Dungan Formation, as a whole, is thought to constitute a continental slope dipping from east to west.

The westward-deepening basin is ascertained by lithological evidence, as mentioned above, namely, that the thickness of the limestone beds intercalated with the Paleocene siltstone in the Zinda Pir area are thinner in the western section than in the eastern ones (Figure 6). Moreover, petrographic studies of these intercalated limestones from the Rakhi Nala show an abundant pelagic faunas (Figure 11A), while some limestone bands from the Zinda Pir area contain deformed or broken specimens of

larger foraminifers along with many glauconite grains (Figure 11B), indicating a shallow marine environment. Actually, these thin limestone bands are of turbidite origin and were emplaced in the deep-water siltstone sequence, possibly due to unstable tectonics in tectonic episodes. Our interpretation is also supported by Humayon *et al.* (1991), who have reported the westward-deepening-basin structure of the Sulaiman fold belts using seismic reflections and drilling core data.

Conclusions

Five biostratigraphic zones P3 to P7 of the tropical zones were recognized in the Dungan Formation exposed in the eastern Sulaiman Range. Zones P3 and P4 are subdivided into two subzones (Subzones A and B). The Dungan Formation is assigned to the late Paleocene to early Eocene. Based on quantitative analysis of planktic species of P-ratios, species richness and species diversity, the Dungan Formation is thought to have been deposited in a relatively deep-water environment, forming a westward-dipping continental slope during the late Paleocene to early Eocene.

Systematic description

Superfamily Rotaliporaceae Sigal, 1958

Family Hedbergellidae Loeblich and Tappan, 1961

Genus *Globanomalina* Haque 1956

Globanomalina rakhiensis sp. nov.

Figure 12

Description.—Test very small, spiral side flat to slightly convex, umbilical side low convex; equatorial periphery elongate, distinctly lobulate; peripheral margin acute, strongly to moderately compressed with a keel; 14 or 15 chambers arranged in 3 whorls, all visible from spiral side; commonly five (rarely six) chambers in the last whorl increase very rapidly in size; on umbilical side intercameral sutures depressed and weakly curved whereas strongly recurved and limbate on spiral side; surface finely perforate; umbilicus narrow and shallow; aperture low arch-shaped, interiomarginal, umbilical-extraumbilical with distinct lip.

Type and material.—Holotype, IGUT (Institute of Geosciences, University of Tsukuba) coll. cat. no. 50101, from Sample R41, Dungan Formation, Rakhi Nala section, maximum diameter 0.27 mm, width 0.20 mm. Paratype, IGUT coll. cat. no. 50102, Sample R41, Dungan Formation, Rakhi Nala section, maximum diameter 0.27 mm, width 0.20 mm. Paratype, IGUT coll. cat. no. 50103, Sample R41, Dungan Formation, Rakhi Nala section, maximum diameter 0.26 mm, width 0.21 mm.

Remarks.—The species is common in Sample R41. The largest specimen is 0.27 mm in diameter, but specimens are usually less than 0.15 mm. *Globanomalina rakhiensis* sp. nov. is a small but very distinctive species and might have been overlooked previously due to its small size. It can be missed if using the 150 µm size fraction. This species shows variation in size and degree of compression of the peripheral margin. The holotype (Figure 12.1–12.3) is less

compressed than the paratype (Figure 12.6 – 12.8). *Planorotalites pseudoscutula* (Glaessner, 1937) is very similar to *G. rakhiensis* sp. nov. but differs in having more chambers in the last whorl (6 or 7) and a circular periphery, and in being more lenticular.

Globanomalina rakhiensis sp. nov. is a homeomorph of the late Paleocene *Globanomalina pseudomenardii* (Bolli, 1957) as both forms possess a compressed planoconvex test, 5 chambers in the last whorl, and a low-arched umbilical-extraumbilical aperture that bears a lip. *G. rakhiensis* sp. nov. is easily distinguished from *G. pseudomenardii* by its small size and relatively weak keel.

The stratigraphic range of *G. pseudomenardii* is restricted to Zone P4 (late Paleocene) in many works (Toumarkine and Luterbacher, 1985; Berggren and Miller, 1988, Berggren *et al.*, 1995; Berggren and Norris, 1997; Olsson *et al.*, 1999, etc). However, Blow (1979) extended the age range of this species to his Zone P7 (early Eocene). We suggest that *Globorotalia* (*G.*) *pseudomenardii* identified by Blow (1979) from his Zone P7 (pl. 111, figs. 1–4; pl. 112, figs. 2, 3; 9–10) is quite similar to our new species (*G. rakhiensis*). Therefore, he might have misidentified *G. rakhiensis* sp. nov.

This new species is named after a local river, Rakhi Nala, along which this section is exposed.

Stratigraphic range.—*Globanomalina rakhiensis* sp. nov. yielded by Sample R41 is assigned to the *M. formosa* Zone (P7), corresponding to Zone P7 of Berggren and Miller (1988) and Berggren *et al.* (1995). Therefore, the stratigraphic range of this species is within the middle lower Eocene.

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Russian)

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Appendix 1: Faunal reference list

The classification of the planktic foraminifera adopted in this paper is based on Berggren *et al.* (1995), Berggren and Norris (1997) and Olsson *et al.* (1999). The synonymies of the planktic foraminifers are restricted to original descriptions. The SEM photographs of marker species are presented in Figures 13 to 18.

- Acarinina coalingensis* (Cushman and Hanna) (Figure 14.17–14.19)
Globigerina coalingensis Cushman and Hanna, 1927, p. 205, pl. 14, fig. 4.
Acarinina esnaensis (LeRoy) (Figure 18.21, 18.22, 18.26)
Globigerina esnaensis LeRoy, 1953, p. 31, pl. 6, figs. 8–10.
Acarinina mckannai (White) (Figure 14.1–14.3)
Globigerina mckannai White, 1928, p. 194, pl. 27, figs. 16a–c.
Acarinina nitida (Martin) (Figure 14.4–14.5, 14.10)
Globigerina nitida Martin, 1943, p. 115, pl. 7, figs. 1a–c.
Acarinina quetra (Bolli) (Figure 17.13–17.15)
Globorotalia quetra Bolli, 1957, p. 79–80, pl. 19, figs. 1–6.
Acarinina pentacamerata (Subbotina) (Figure 17.16–17.18)
Globorotalia pentacamerata Subbotina, 1947, p. 128–129, pl. 12–17, figs. 24–26.
Acarinina pseudotopilensis Subbotina (Figure 18.15–18.17)
Acarinina pseudotopilensis Subbotina, 1953, p. 227–228, pl. 21, figs. 13.
Acarinina soldadoensis angulosa (Bolli) (Figure 17.19–17.20, 17.26)
Globigerina soldadoensis angulosa Bolli, 1957, p. 71, pl. 16, figs. 46.
Acarinina soldadoensis soldadoensis (Bronnimann) (Figure 14.6, 14.11–14.15)
Globigerina soldadoensis Bronnimann, 1952, p. 7, 9, pl. 1, figs. 19
Acarinina strabocella (Loeblich and Tappan) (Figure 13.15–13.17)
Globorotalia strabocella Loeblich and Tappan, 1957, p. 195, pl. 61, figs. 6a–c.
Acarinina subsphaerica (Subbotina) (Figure 14.7–14.9)
Globigerina subsphaerica Subbotina, 1947, p. 108, pl. 5, figs. 26–28.
Acarinina wilcoxensis (Cushman and Ponton) (Figure 13.4, 13.5, 13.9)
Globorotalia wilcoxensis Cushman and Ponton, 1932, p. 71, pl. 9, figs. 10a–c.
Chiloguembelina crinita (Glaessner) (Figure 18.9–18.10)
Guembelina crinita Glaessner, 1937, p. 383, pl. 4, figs. 34a, b.
Chiloguembelina trinitatis (Cushman and Renz) (Figure 17.24–17.25)
Guembelina trinitatis Cushman and Renz, 1942, p. 8, pl. 2, figs. 8a, b
Chiloguembelina wilcoxensis (Cushman and Ponton) (Figure 18.27–18.28)
Guembelina wilcoxensis Cushman and Ponton, 1932, p. 66, pl. 8, figs. 16, 17.
Globanomalina chapmani (Parr) (Figure 13.1–13.3)
Globorotalia chapmani Parr, 1938, p. 87, pl. 3, figs. 8, 9.
Globanomalina compressa (Plummer)
Globigerina compressa Plummer, 1926, p. 135, pl. 8, figs. 11a–c.
Globanomalina ehrenbergi (Bolli) (Figure 15.18–15.20)
Globorotalia ehrenbergi Bolli, 1957, p. 77, pl. 20, figs. 18–20.
Globanomalina elongata (Glaessner)
Globanomalina pseudoscutula var. *elongata* Glaessner, 1937, p. 33, pl. 1, figs. 3d–f.
Globanomalina imitata (Subbotina) (Figure 15.13–15.15; 15.22–15.24)
Globorotalia imitata Subbotina, 1953, p. 206–207, pl. 16, figs. 14–16.
Globanomalina pseudomenardii (Bolli) (Figure 15.16–15.17, 15.21)
Globorotalia pseudomenardii Bolli, 1957, p. 77, pl. 20, figs. 14–17.
Igorina albeari (Cushman and Bermudez) (Figure 13.10, 13.14, 13.18)
Globorotalia albeari Cushman and Bermudez, 1949, p. 33, pl. 6, figs. 13–15.
Igorina broedermanni (Cushman and Bermudez) (Figure 18.18–18.20)
Globorotalia (Truncorotalia) broedermanni Cushman and Bermudez, 1949, p. 40, pl. 7, figs. 22–24.
Igorina pusilla (Bolli) (Figure 13.19–13.21)
Globorotalia pusilla pusilla Bolli, 1957, p. 78, pl. 20, figs. 8–10.
Igorina tadjikistanensis (Bykova) (Figure 13.11–13.13)
Globorotalia tadjikistanensis Bykova, 1953, p. 86, pl. 3, figs. 5a–c.
Morozovella acuta (Toulmin) (Figure 16.1–16.3; 16.4–16.5, 16.10)
Globorotalia wilcoxensis Cushman and Ponton var. *acuta* Toulmin, 1941, p. 608, pl. 82, figs. 68.
Morozovella acutispira (Bolli and Cita) (Figure 16.7–16.9)
Globorotalia acutispira Bolli and Cita, 1960, p. 15, pl. 33, figs. 3a–c.
Morozovella aequa (Cushman and Renz) (Figure 16.20–16.21, 16.25)
Globorotalia crassata (Cushman) var. *aequa* Cushman and Renz, 1942, p. 12, pl. 3, figs. 3a–c.
Morozovella aragonensis (Nuttall) (Figure 17.6, 17.11, 17.12)
Globorotalia aragonensis Nuttall, 1930, p. 288, pl. 24, figs. 6–11.
Morozovella angulata (White) (Figure 15.1–15.3)
Globigerina angulata White, 1928, p. 191, 192, pl. 27, figs. 13a–c.
Morozovella apantesma (Loeblich and Tappan) (Figure 16.6, 16.11, 16.12)
Globorotalia apantesma Loeblich and Tappan, 1957, p. 187, pl. 48, figs. 1a–c, pl. 55, figs. 1a–c, pl. 58, figs. 4a–c; pl. 59, figs. 1a–c.
Morozovella conicotruncata (Subbotina) (Figure 15.7–15.9)
Globorotalia conicotruncata Subbotina, 1947, p. 115–117, pl. 4, figs. 11–13; pl. 9, figs. 9–11.
Morozovella edgari (Primoli Silva and Bolli) (Figure 17.1–17.3)
Globorotalia edgari Primoli Silva and Bolli, 1973, p. 526, pl. 7, figs. 10–12, pl. 8, figs. 1–12.

- Morozovella formosa formosa* (Bolli) (Figure 17.21–17.23)
Globorotalia formosa formosa Bolli, 1957, p. 76, pl. 18, figs. 1–3.
Morozovella formosa gracilis (Bolli) (Figure 16.13–16.15)
Globorotalia formosa gracilis Bolli 1957, p. 75, 76, pl. 18, figs. 4–6.
Morozovella lensiformis (Subbotina) (Figure 17.7–17.9)
Globorotalia lensiformis Subbotina, 1953, p. 214, pl. 18, figs. 4, 5.
Morozovella marginodentata (Subbotina) (Figure 17.4, 17.5, 17.10)
Globorotalia marginodentata Subbotina, 1953, p. 212, 213, pl. 17, figs. 14–16, pl. 18, figs. 1–3.
Morozovella occlusa (Loeblich and Tappan) (Figure 16.22–16.24)
Globorotalia occlusa Loeblich and Tappan, 1957, p. 191, pl. 64, figs. 3a–c.
Morozovella subbotinae (Morozova) (Figure 15.4, 15.5, 15.10)
Globorotalia subbotinae Morozova, 1939, p. 80, pl. 2, figs. 16, 17.
Morozovella velascoensis (Cushman) (Figure 16.17–16.19)
Pulvinulina velascoensis Cushman, 1925, p. 19, pl. 3, figs. 5a–c.
Parasubbotina varianta (Subbotina) (Figure 13.6–13.8)
Globigerina varianta Subbotina, 1953, p. 63, pl. 3, figs. 5–7, 10–12.
Planorotalites pseudoscutula (Glaessner) (Figure 18.23–18.25)
Globorotalia pseudoscutula Glaessner, 1937, p. 32, figs. 3a–c.
Pseudohastigerina wilcoxensis (Cushman and Ponton) (Figure 15.6, 15.11, 15.12)
Nonion wilcoxensis Cushman and Ponton, 1932, p. 64, pl. 8, figs. 11a, b.
Subbotina inaequispira (Subbotina) (Figure 18.6–18.8)
Globigerina inaequispira Subbotina, 1953, p. 69, pl. 6, figs. 1–4.
Subbotina lozanoi (Colom) (Figure 18.1–18.3)
Globigerina lozanoi Colom, 1954, p. 149, pl. 2, figs. 1–48.
Subbotina patagonica (Todd and Kniker) (Figure 18.4, 18.5, 18.11)
Globigerina patagonica Todd and Kniker, 1952, p. 26, pl. 4, figs. 32a–c.
Subbotina prolata (Bolli) (Figure 18.12–18.14)
Globigerina prolata Bolli, 1957, p. 72, pl. 15, figs. 24–26.
Subbotina triangularis (White) (Figure 14.22–14.24)
Globigerina triangularis White, 1928, p. 195, pl. 28, figs. 1a–c.
Subbotina triloculinoides (Plummer) (Figure 14.25–14.27)
Globigerina triloculinoides Plummer, 1926, p. 134, 135, pl. 8, figs. 10a–c.
Subbotina velascoensis (Cushman) (Figure 14.16, 14.20, 14.21)
Globigerina velascoensis Cushman, 1925, p. 19, pl. 3, figs. 6a–c.
Turborotalia praecentralis Blow
Globorotalia (Turborotalia) praecentralis Blow, 1979, p. 1094, pl. 135, figs. 7–9; pl. 136, figs. 1–6; pl. 233, fig. 6.

Appendix 2: Stratigraphic distribution and relative abundance (%) of planktic foraminiferal species in the Dungan Formation exposed at the Rakhi Nala section. Here x = less than 1 %.

Dungan Formation																Samples	Planktic foraminiferal species
R23	R28	R25	R29	R30	R32	R26	R27	R33	R34	R35	R36	R38	R39	R40	R41		
	2	3	1	2	6	6	x	1	x	6	1		3	2	4		<i>Acarinina coalingensis</i>
								x	x		2		1		1		<i>A. esnaensis</i>
	1		1	1		2											<i>A. mckannai</i>
	2	2	2	2	4	2	4	2		4	2						<i>A. nitida</i>
											3	5	3	10	4		<i>A. pentacamerata</i>
							2	x	1	1	1	2	4	1	3		<i>A. pseudotopilensis</i>
											3	1	1	5	4		<i>A. quetra</i>
			10	3	13	11	14	18	8	28	22	25	31	36	19		<i>A. sold. soldadoensis</i>
	4										2	3	3	5	5		<i>A. soldadoensis angulosa</i>
																	<i>A. strabocella</i>
		1	1	1													<i>A. subsphaerica</i>
							1		3	13	11	4	6	4	7		<i>A. wilcoxensis</i>
			1				1	1									<i>Chiloguembelina crinita</i>
				2													<i>Ch. trinitatensis</i>
					x			1									<i>Ch. wilcoxensis</i>
		1		1													<i>Globanomalina chapmani</i>
	1		2	3													<i>G. ehrenbergi</i>
						1											<i>G. elongata</i>
x	1	1		1	x	1											<i>G. imitata</i>
		2	8	14	1												<i>G. pseudomenardii</i>
																5	<i>G. rakhiensis</i>
	6		1	1													<i>Igorina albeari</i>
							1		1	4	3	2	3	2	4		<i>I. broedermanni</i>
	7	1	1	1													<i>I. pusilla</i>
3	4	3	4	4	4	3											<i>I. tadjikistanensis</i>
46	9	58	14	17	33	23	9	11									<i>Morozovella acuta</i>
		x	1		x												<i>M. acutispira</i>
4	6	2	1	x	5	3	3	1	3	1	1		x				<i>M. aequa</i>
18	37	1															<i>M. angulata</i>
3		1	5	3		1											<i>M. apantesma</i>
									3	3	11	13	7	8	14		<i>M. aragonensis</i>
	2	5	3	2		1											<i>M. conicotruncata</i>
							11	1	1								<i>M. edgari</i>
								1	1	1	1	1	x	x	1		<i>M. formosa formosa</i>
					1	1	5	4	4	2	5				2		<i>M. formosa gracilis</i>
									3	4	10	9	6	7	2		<i>M. lensiformis</i>
									6	6	2	2			1		<i>M. marginodentata</i>
		3	4	2	1	5	2	5									<i>M. occlusa</i>
					4	4	30	20	35	12	14	9	6	5	x		<i>M. subbotinae</i>
	2	3	16	11	3	1		17									<i>M. velascoensis</i>
	1																<i>Parasubbotina varianta</i>
													6	2	4		<i>Planorot. pseudoscutula</i>
							3	1	5	2	1	2	2		4		<i>Pseudohast. wilcoxensis</i>
												2	3	1	5		<i>Subbotina inaequispira</i>
															6		<i>S. lozanoi</i>
										3		1	1	2	4		<i>S. prolata</i>
							6	8	14	8	2	12	14	3	2		<i>S. patagonica</i>
2	1	1		2		3											<i>S. triloculinoides</i>
23	12	11	19	16	19	26	8	5	12	3	3	7					<i>S. triangularis</i>
	3	3	7	7	5	9	x	1									<i>S. velascoensis</i>
												3					<i>Turborotalia praecentralis</i>
226	393	308	383	409	298	343	316	288	305	187	262	199	304	243	301		Total Counts
8	18	19	20	22	15	18	17	19	16	17	20	18	19	18	20		Species Number
P3B			P4A	P4B	P5	P7										Zones	

Appendix 3: Stratigraphic distribution and relative abundance (%) of planktic foraminiferal species in the Dungan Formation exposed along the eastern and western limbs of the Zinda Pir Anticline. Here x = less than 1 %.

Dungan Formation			Western side										Planktic foraminiferal Species																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
			Samples	Acaritina coalingensis		A. mckennai		A. nitida		A. soldadoensis soldadoensis		A. strabocella		A. subsphearica		A. wilcoxensis		Globanomalina chapmani		G. compressa		G. ehrenbergi		G. imitata		G. pseudomenardii		Igorina albeari		I. pusilla		I. tadjikistanensis		Morozovella acuta		M. acutispira		M. aequa		M. angulata		M. apantesma		M. conicotruncata		M. formosa gracilis		M. oclusa		M. subbotinae		M. velascoensis		Parasubbotina varianta		Pseudohastigerina wilcoxensis		Subbotina triliculoides		S. triangularis		S. velascoensis		Total Counts		Species Number																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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